REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
07/00/83

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
REGIONAL GROUNDWATER STUDY OF ROCKY MOUNTAIN ARSENAL, REPORT 2, CONTAMINANT DISTRIBUTION

5. FUNDING NUMBERS

6. AUTHOR(S)
SPAINE, P.; THOMPSON, D.; DILDINE, J.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ARMY ENGINEER WATERWAYS EXPERIMENT STATION. ENVIRONMENTAL LABORATORY
VICKSBURG, MS

8. PERFORMING ORGANIZATION REPORT NUMBER
84100R01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
ABERDEEN PROVING GROUND, MD

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)
THIS REPORT DOCUMENTS THE COLLECTION AND ANALYSIS OF GROUND WATER SAMPLES AND PRESENTS CONTAMINANT DISTRIBUTION AND PLUME MAPS DEVELOPED FROM DATA COLLECTED IN THE REGIONAL STUDY AND PREVIOUS STUDIES AT RMA. THE HYDROGEOLOGIC PORTION OF THE REGIONAL STUDY HAS BEEN DOCUMENTED IN A REPORT ENTITLED: REGIONAL GROUND WATER STUDY OF RMA, REPORT 1, HYDROGEOLOGICAL DEFINITION, JULY 1981 (82295R01).

14. SUBJECT TERMS
CHEMICALS, SAMPLING, QUANTITATIVE RESULTS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

REGIONAL GROUND-WATER STUDY OF ROCKY MOUNTAIN ARSENAL
REPORT 2: CONTAMINANT DISTRIBUTION

by

Patricia A. Spaine
Douglas W. Thompson
Jack H. Dildine

Environmental Laboratory
US Army Engineer Waterways Experiment Station
P.O. Box 631, Vicksburg, MS 39180

July 1983

Prepared for: US Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland 21010
and: Rocky Mountain Arsenal
Commerce City, CO 80240
Under: RMA Task R01.011

PREFACE

This investigation was conducted during the period April 1980 to February 1983 by personnel of the Geotechnical Laboratory (GL) and Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES) under the Contamination Control Program of the Rocky Mountain Arsenal (RMA), Commerce City, CO. Funding for this study was authorized by the U. S. Army Toxic and Hazardous Materials Agency (USATHAMA). This study was under RMA Task R01.011.

This report (Report 2 of 2) was written by Ms. P. A. Spaine and Messrs. D. W. Thompson and J. H. Dildine, Water Supply and Waste Treatment Group (WSWTG), Environmental Engineering Division (EED), EL. The report on hydrogeological definition (Report 1 of 2, see Ref. 2) was written by Mr. J. H. May, Engineering Geology Application Group (EGAG), Engineering Geology and Rock Mechanics Division (EGRMD), GL. The report was prepared under the direct supervision of Mr. N. R. Francingues, Chief, WSWTG. Report 1 was prepared under the direct supervision of Mr. J. H. Shamburger, Chief, EGAG. General supervision was provided by Mr. A. J. Green, Chief, EED, and Dr. D. C. Banks, Chief, EGRMD, Dr. J. Harrison, Chief, EL, and Dr. W. F. Marcuson III, Chief, GL.

Special acknowledgement is extended to the following individuals for their assistance during this study: Mr. E. W. Berry, Dr. W. McNeill, Dr. M. E. Witt, Messrs. Brian Anderson, Greg Ward, and Bill Trautman of RMA; Messrs. Don Campbell, Jack Scott, and Al McKinney of USATHAMA.

Commanders and Directors of WES during this study were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

	Page
PREFACE	2
PART I: INTRODUCTION	4
Background	4
Purpose and Scope	5
Approach	7
PART II: METHODS	9
Qualitative	9
Semi-Quantitative	10
Quantitative	11
PART III: RESULTS AND DISCUSSION	13
Qualitative Results	13
Semi-Quantitative Assessment and Quantitative Program Design	14
Quantitative Results	15
Summary of Ground-Water Contaminant Migration	20
Investigation of Contaminant Stratification Along the Northwest Boundary	22
PART IV: CONCLUSIONS AND RECOMMENDATIONS	23
Conclusions	23
Recommendations	23
REFERENCES	25
TABLES	26
FIGURES	30

REGIONAL GROUND-WATER STUDY OF ROCKY MOUNTAIN ARSENAL
REPORT 2: CONTAMINANT DISTRIBUTION

PART I: INTRODUCTION

Background

The Rocky Mountain Arsenal (RMA) is located northeast of the city of Denver, Colorado adjacent to Stapleton International Airport. The Arsenal began operation in 1942 producing chemical munitions and later conducted demilitarization of chemical munitions. Since 1946, a variety of private firms have leased facilities at the Arsenal for use in producing herbicides and pesticides. Lessee chemical manufacturing has been concentrated in the South Plants area (see Figure 1) while the GB Plant or North Plant complex has been used for nerve agent productions, munitions filling, and demiling of munitions.

From 1942 to 1956, chemical wastes generated from both Army and private activities on the Arsenal were disposed of in Basin A located just north of the South Plants area. Alternate and overflow discharges were collected in Basins B, C, D, and E. These basins were unlined and generally constructed in natural depressions.

Crop damage was observed in 1951 through 1954 in areas north of the Arsenal where shallow wells were being utilized for irrigation. Investigations conducted during this period of time indicated that liquid wastes had seeped from the unlined disposal basins, infiltrated the shallow alluvial aquifer, and migrated down gradient toward the South Platte River. To prevent additional contamination of the alluvial aquifer, a 92 acre evaporation basin (Basin F) was constructed in 1956 with an asphalt liner. Process wastes in storage in the other basins on the Arsenal were subsequently transferred to Basin F. Additional wastes generated on the Arsenal after 1956 were disposed of in Basin F.

In 1974, contaminants were detected in surface and subsurface waters outside the boundary of RMA and in April 1975 the Colorado Department of Health (CDH) issued three Cease and Desist Orders with respect to the operations at RMA. Subsequent investigations and studies directed by the US Army Toxic and Hazardous Materials Agency (USATHAMA) were conducted to identify, control, and treat contaminated ground water.

In the 1970's many geotechnical and hydrogeological studies were conducted at RMA by both government agencies and private contractors. These studies were generally restricted to small geographical areas, limited objectives, and shallow borings. Results of these studies indicated that the contaminants were concentrated primarily in the alluvial sand and gravel deposits with minor amounts of contaminants found in the underlying clay shales, silts, and sands of the Denver Formation. Although the studies were thorough and produced results and conclusions consistent with the limited forms of each study, it was hard to compare the results from one study to the next and to link the results to form a regional assessment of conditions. In addition, there were large areas of the Arsenal that had never been investigated due to a lack of evidence of any contamination.

During the first and second quarters of FY80, the firm of Geraghty and Miller, Inc. was tasked to perform an overall assessment and integrated evaluation of the geotechnical and hydrogeological data contained in technical reports on previous studies, the USATHAMA computerized data base, and records and data files maintained at RMA. The results of the data assessment and evaluation were documented in a report entitled "Evaluation of the Hydrogeologic System and Contaminant Migration Patterns at RMA" (1). the report recommended that further geotechnical field investigations be initiated to provide additional information on a regional scale to address data gaps in the areas of geology, hydrology, and ground-water quality.

In response to the report recommendations, a new geotechnical investigation known as the Regional Study was initiated based on input from representatives of USATHAMA, RMA, USAE Waterways Experiment Station (WES), and Geraghty and Miller, Inc. The WES Geotechnical Laboratory (GL) and Environmental Laboratory (EL) were tasked to conduct the investigation with support from RMA.

Purpose and Scope

The purpose of the Regional Study at RMA was to meet the following objectives as stated in the FY 80/81 Geotechnical Program Implementation Plan:

(a) Objective 1 - To collect hydrogeologic data along the northwest boundary to provide a generalized concept for preventing contaminated ground water from exiting RMA. These data were to be used as input to update an existing DD 1391 which was due 1 Aug 80. The area of concern during the

June 80 period was the area of the northwest boundary near 9th Avenue. (Note: The Nemagon plume exiting the Arsenal along the northwest boundary near 8th Avenue at Irondale had not been detected when the study was started.)

(b) Objective 2 - Provide data concerning hydrologic and lithologic conditions over the entire Arsenal. The study was to use an Arsenal-wide or a regional approach which would define the quantity, the rate of movement and quality of groundwater flowing onto the Arsenal, under the Arsenal, and exiting at the Arsenal boundary. The study was planned to provide the following information: (1) water table gradients throughout the Arsenal, (2) local flow directions, (3) identification of contaminated sources, (4) delineation of contaminant plumes and changes in plume concentration, (5) rate of contaminant movement, (6) volume of contaminated water for design of treatment systems, and (7) water level changes with time.

To achieve these objectives, a number of boring and observation wells were constructed within the Arsenal boundaries. Corings were taken for physical analysis. All borings were logged prior to installation of casings. Selected pump tests were conducted. Ground-water samples were collected and analyzed. The resulting data were interpreted, evaluated, and plotted on maps or cross-sections as appropriate. The data collection, interpretation, and report preparation responsibilities for this study were assigned as follows:

WES Geotechnical Laboratory -	drilling and well installation, physical analysis of cores, pump tests, water level monitoring, hydrogeologic interpretation, and report preparation.
Rocky Mountain Arsenal -	ground-water sampling protocol development, sample collection and preparation, chemical analysis of samples, and data management.
WES Environmental Laboratory -	chemical analysis of samples, interpretation of chemical data, definition of contaminant distribution, and report preparation.

The hydrogeologic portion of the Regional Study has been documented in a report entitled "Regional Groundwater Study of Rocky Mountain Arsenal, Report 1: Hydrogeological Definition," (2). The report presented herein documents the collection and analysis of ground-water samples and presents contaminant distribution and plume maps developed from data collected in the Regional Study and previous studies at RMA.

Approach

Based on discussions among personnel from WES, RMA, USATHAMA, and Geraghty and Miller, Inc., 69 well sites were selected to provide the data needed to meet the above two objectives (see Figure 2). At 66 of the drilling sites, three individual piezometers were placed; one in the alluvium and one in each of the first two water-bearing Denver sands encountered during drilling. Three of the sites (NW1, 4 and 11) were selected for installation of multi-piezometers in the alluvial aquifer to determine if contaminant stratification was occurring along the northwest boundary.

The ground-water sampling and analysis program consisted of three phases: Qualitative, Semi-Quantitative, and Quantitative. The Qualitative phase was designed as contaminant screening technique to determine what piezometers produced contaminated ground water and to insure that all contaminants at the Arsenal were identified. The goal of this phase was to rapidly screen a long list of potential contaminants and identify those which should be specifically analyzed for in the Quantitative phase of the program. This technique greatly reduced the analytical work load later in the program by eliminating the need to analyze each ground-water sample for a lengthy "laundry list" of contaminants. The samples subjected to qualitative analysis were spiked with a known amount of a standard to provide a basis for conducting the Semi-Quantitative phase of the program. In this phase of the program, approximate concentration of the contaminants were calculated based on a comparison with the amount of spiked standard added to each sample. This information was used as an aid to personnel collecting and analyzing the samples. By knowing the approximate concentrations of contaminants in a particular sample, the personnel collecting the samples could assess the potential for cross contamination of samples from sampling equipment and modify the sampling procedures accordingly. This information also aided the analyst by providing an indication of concentration range thereby reducing the number of dilutions and reruns required during analysis of each sample.

As originally proposed, the Quantitative phase was to have consisted of three rounds of sample collection and analysis. After the first round of sampling and analyses were completed, USATHAMA terminated the program and transferred the remaining resources to other ground-water monitoring programs ongoing at the Arsenal. The data obtained from the Quantitative phase of the

program along with available data from other historical and ongoing monitoring programs at RMA were used to develop the contaminant plume maps presented in this report.

PART II: METHODS

Qualitative

The Qualitative phase of the program was conducted during the 3rd and 4th quarters of FY81. Of the 211 piezometers placed for the program, eight were found to be consistently dry and three others did not produce sufficient quantities of water required for analysis. Each of the 200 remaining piezometers was ev were allowed to recover for a period of four to six days prior to sampling. Stainless steel bailers were used to remove five to six bailer volumes immediately prior to collection of the ground-water sample. The sample was split into two samples in the field, one for volatile organics analysis and one for extractable organic analysis. The samples were transferred daily to the RMA laboratory receiving area in glass jars with ground glass stoppers. The samples were kept iced in insulated chests during transport and storage.

The qualitative analyses of the samples were conducted by the RMA and WES analytical laboratories. The RMA laboratory conducted the volatile organic analyses using EPA's Method 624 (FR Vol. 44, No. 233, Dec 3, 1979) and extracted the samples for extractable organic analysis using the following procedure.

a. 1000 ml water sample added to 2-liter separatory funnel.
b. 100 nanograms gama-BHC (Lindane) added to the water sample.
c. Extract water sample three times with 60 ml of distilled-in-glass methylene chloride with 10 minute waits between each extraction for phase separation between the water and methylene chloride interface.
d. Combine extracts and remove water by adding pre-extracted anhydrous sodium sulfate to the flask.
e. Filter dried extract through a pre-extracted filter into a Kuderna-Danish setup and concentrate to one milliliter.
f. Prepare a solvent blank with each lot of samples by following above procedures except with the elimination of steps a and b.

The extracts were shipped to WES packed in dry ice to reduce loss of sample by evaporation. The extracts were analyzed by the WES laboratory using EPA's Method 625 (FR Vol. 44, No. 233, Dec 3, 1979). The Lindane added to the samples prior to extraction was used to verify the extraction procedure and to

determine if any evaporation of the extracts occurred during shipment. The detection limits for the qualitative analyses ranged from 20 to 50 ppb depending on the contaminant and sample.

In order to use the results from the qualitative analysis of the samples in the Semi-Qualitative phase of the program, two internal standards (bromochloromethane and 1,4-dichlorobutane) were spiked in the volatile organics splits prior to analysis while d-10 anthracene was spiked in the extracts prior to analysis. None of these organics have ever been found in the groundwater at RMA and thus were suitable for use as internal standards.

Semi-Quantitative

The semi-quantitative results were calculated using the data obtained from the qualitative analysis of the spiked samples. The sample spectra generated during the qualitative analysis were recalled from the computer data files and examined. The approximate concentration of each contaminant identified was estimated by comparing its peak to that of the internal standard peak nearest it on the chromatogram. Based on the estimated concentration, three standard methanol solutions containing concentrations of a particular contaminant below, at, and above the estimated concentration were prepared. Each of the three standard solutions was spiked with a sufficient amount of internal standard (the same standard used to spike the groundwater samples) to produce a concentration of 10 ppb in 50 ml of organic-free water. Each standard solution was analyzed on the same GC/MS system using the same conditions (as near as possible) as were used to conduct the qualitative analyses. The results obtained were used to calculate an equipment response factor for each contaminant. These response factors along with the original chromatograms from the qualitative analyses (specifically the area under each peak) and the known concentration of the internal standard were use to calculate the concentrations of the contaminants in the ground-water samples. The RMA analytical laboratory conducted the semi-quantitative work on the volatile organics while the WES analytical laboratory conducted the work on the extractable organics.

Quantitative

Sample collection for the Quantitative phase of the program was initiated during the 3rd quarter of FY82. The sampling technique used was based on a sampling protocol developed by Ertec Western, Inc. (3). This protocol was modified by RMA to accommodate specific field conditions, project schedule limitations and available manpower and economic resources at RMA. Details of the sampling technique used to collect ground-water samples for the Quantitative phase are summarized below.

a. Piezometers to be sampled were identified and located with a particular sampling crew assigned to sample three piezometers per day.

b. Piezometer construction details were obtained from a well summary report and reviewed to determine well depth and screen location. Based on the known well conditions (i.e. depth, degree of contamination, amount of water required to be removed, conditions of the casing, etc.), the appropriate sampling equipment (either pump or bailer) was identified.

c. At the site, the water level in the piezometer was measured and recorded. This information was used to calculate the volume of water contained in the casing.

d. Next, three casing volumes of water were removed from the piezometer. In areas of low permeability where the piezometers would not produce three casing volumes of water, the piezometers were pumped or bailed dry and allowed to recover prior to sample collection. All water removed prior to sampling was collected and discharged on the ground at a minimum distance of 50 feet down gradient from the sampling site. The amount of water removed was recorded in a field log book.

e. A number of sample splits were collected for the various analyses to be performed. The splits for extractable organic analyses were collected in 1000-ml amber bottles with teflon lined caps. The splits for volatile organic analyses were collected in 40-ml volatile vials with crimped caps containing teflon septums. These vials were completely filled prior to capping to eliminate any head space. Splits for metals analyses were filtered in the field through a 0.45-micron membrane filter, placed in a 250-ml polyethylene bottle, and acidified with nitric acid to a pH of less than 2.

f. Immediately after collection, field measurements of pH, conductivity, and temperature were made and recorded in the log book.

g. All samples were labeled and recorded and the containers stored in iced coolers for transfer to the laboratory where they were refrigerated.

h. The sampling equipment was thoroughly cleaned prior to moving to the next collection site and at the end of each day using hot detergent water, solvent, and deionized water as appropriate.

The sample analyses were performed by the RMA laboratory and by Midwest Research Institute (MRI) of Kansas City. Table 1 provides a breakout of the analyses conducted by each lab and the detection levels required to be achieved. All analytical methods were prescribed by USATHAMA. MRI was required by USATHAMA to conduct qualification program prior to initiation of sample analyses. Sample splits for MRI were shipped to Kansas City by air under chain-of-custory procedures. Both labs conducted internal quality control programs during all of the sample analysis period. Specific information on the analytical protocols used and the quality control programs conducted is on file at the RMA lab, MRI, and USATHAMA.

PART III: RESULTS AND DISCUSSION

A large volume of analytical data was generated during the three phases of this study. The raw data are in the form of chromatograms, ion spectra, and various types of computer printouts which are difficult to reproduce in report form and are difficult to read and interpret due to their format and the abbreviations and codes used by the computers. Therefore, the raw analytical data have not been reproduced in this report. All the data reports have been collected from the various laboratories, organized, and are available for review at the Rocky Information Center (RIC) located at RMA. All data have been reviewed, evaluated, and summarized in the form of a series of contaminant distribution and plume maps for presentation in this report. A discussion of these maps and the results of each phase of the study follows.

Qualitative Results

As previously discussed, the objective of the Qualitative phase was to screen the Arsenal ground water for both historical and unknown contaminants and to determine areas of ground-water contamination. The results of the qualitative analyses are summarized and presented on six maps (Figures 3-8). These maps provide a graphic illustration of the distribution of the identified contaminants. On each map, a specific symbol is used to identify each contaminant found in the ground-water sample collected from each piezometer.

The DIMP and DCPD distribution map is presented as Figure 3. These contaminants were identified in the ground water from piezometers in the Basin A Neck Area, along the Northwest Boundary and between Basin F and the North Boundary. Toluene, xylene, and benzene distributions are presented in Figure 4. These volatiles were identified in piezometers scattered across the Arsenal as was chloroform, the distribution of which is presented in Figure 5.

Di-, tri-, and tetrachloroethylene distributions are presented in Figure 6 showing only a few piezometers scattered across the Arsenal intercepting ground water containing these contaminants. The distribution of benzothiazole and other organo-sulfur compounds are presented in Figure 7. Benzothiazole was found to have the widest distributions across the Arsenal of the organo-sulfur compounds. The other sulfur compounds were identified in ground water from a few piezometers scattered across the Arsenal.

The distributions of tetramethyl urea and napthalene are presented in Figure 8. Tetramethyl urea was identified in ground water from various piezometers located through the central part of the Arsenal including the South Plants Area, Basin A Neck Area, and north and east of Basin F. Napthalene was found in ground water from a limited number of piezometers scattered across the Arsenal.

The results of the qualitative screening indicated only several new contaminants distributed in the ground water at RMA in addition to the historical ones previously monitored. These new contaminants included some volatiles and tetramethyl urea which had not previously been identified on the Arsenal. The results indicated that many of the unique contaminants previously identified only in the South Plants Area have not migrated to other parts of the Arsenal. The qualitative screening did not detect some contaminants known to exist in very low concentrations on the Arsenal, such as DBCP, Aldrin, Endrin, Dieldrin, and Isodrin probably due to the higher detection levels associated with the qualitative analysis. In general, the qualitative screening indicated that quantitative analysis for a large number of contaminants was not necessary to provide a general description of contaminant distribution in the groundwater at RMA.

Semi-Quantitative Assessment and Quantitative Program Design

As previously discussed, estimated concentrations of the contaminants identified during the qualitative analyses were calculated during the Semi-Quantitative phase of the program. Although these results were intended primarily for internal use, they have been tabulated and are available through the RIC.

The results obtained from the qualitative and semi-quantitative analyses were used along with available historical data to develop a sampling and analysis plan for the Quantitative phase of the program. Based on these results, the Arsenal was divided into four sectors containing approximately equal numbers of piezometers to be sampled (see Figure 9). The sectors were established in order that all the piezometers in a single sector would be sampled prior to moving to the next sector to minimize the time difference between sampling of piezometers in one general area. In addition, the analyses to be conducted on each sample was the same throughout all piezometers in each

sector thus simplifying the analytical portion of the program. The sectors were identified as Southern/Eastern (S/E), Central (C), Western (W), and Northern (N). To provide additional data density in some parts of the Arsenal, seventeen well sites including approximately 30 piezometers were selected for inclusion in the sampling and analysis program in addition to the Regional well sites. A list of the Regional well sites and additional piezometers sampled in each sector along with the specific contaminants analyzed for in each sample are presented in Table 2.

Quantitative Results

The analytical results from the Quantitative phase of the Regional Study along with current and historical data collected from other contaminant surveys at the Arsenal were used to develop a series of contaminant plume maps. The data used to develop these maps are primarily associated with ground water from alluvial piezometers, however, data from Denver-formation piezometers have been included, particularly in areas where the alluvium is dry and groundwater flows primarily through the Denver formation. Historical data was used to supplement data from the Regional Study primarily in the South Plants Area and Basin A where few Regional wells were placed. Contaminant concentrations are illustrated where possible using iso-concentration lines and only those contaminants found above detection levels in more than four or five groundwater samples were mapped. It should be noted that the tetramethyl urea identified in the Qualitative phase was not confirmed in Quantitative phase indicating a probable error in identification. Table 3 presents a list of applicable water quality criteria used to determine ground-water areas of unacceptable quality.

Volatile Organics - These components have only recently been quantified in the Regional Program and little or no historical data are available on their distribution. Reportable concentrations of toluene, xylene, benzene, chlorobenzene, chloroform, carbon tetrachloride, dichloroethylene, trichloroethylene, and tetrachloreothylene have been identified. The distribution of these contaminants is such that representative plume maps could not be developed for each compound, but a typical distribution is seen in Figure 10. In many cases, the wells in which these contaminants were identified are scattered, and data

are not sufficient to link the various concentrations together, because of the distances between regional wells. The highest concentrations of these compounds were found in the South Plants Area, suggesting that introduction in the tank farm area. The basins would probably not serve as sources for these compounds because of their volatility when in contact with the atmosphere.

Toluene, xylene, and some of the ethylenes were identified in the southwest corner of the Arsenal. Since these compounds represent organic solvents in wide-spread industrial use, they cannot be identified as unique to RMA. As a result, it is suspected that the concentrations identified in this remote part of the Arsenal that is upgradient from any Arsenal related source is not directly attributable to RMA activities. Some of these compounds are considered "priority pollutants" with recommended criteria in water from non-detectable to a few parts-per-billion concentration.

Chlorinated Pesticides (Aldrin, Dieldrin, Endrin) - Chlorinated pesticides (aldrin, dieldrin, endrin), have in the past been available for public use, but were banned by EPA because of their hazard. These chemicals were manufactured on the Arsenal by a lessee and therefore their distribution is directly associated with Arsenal activities. A water criterion of 0.2 μg/l (ppb) has been established for endrin. The criteria for aldrin and dieldrin is to minimize their presence. Concentrations in excess of the criteria were identified in various parts of the Arsenal. Figures 11, 12, and 13 present the aldrin concentrations and dieldrin and endrin plumes. There were insufficient data to contour the aldrin contamination; however, aldrin was present in the general vicinities where dieldrin and endrin were found. High concentrations of the pesticides were identified west and northwest of the "A-Neck" area. Very high concentrations were identified along the Northwest Boundary. Plumes for dieldrin and endrin are evident exiting the northeast corner of Basin F and continuing to the North Boundary. Concentrations of dieldrin and endrin of 5.0 μg/l and higher have reached the North Boundary of the Arsenal.

The plumes indicate that the South Plants Area and Basin F are currently sources of the pesticides and that Basin A probably served as a source in the past. Some of the traces identified along the northwest boundary could be remnants of historic plumes that have dissipated. However, some of the pesticide concentrations identified in this area could be the result of a migration

along pathways such as from the sanitary or chemical sewers in Sections 35 and 26, or from a spill in the Rail Classification Yard.

Dibromochloropropane - Dibromochloropropane (DBCP) was manufactured on the Arsenal by a lessee and its distribution is directly associated with Arsenal activities. It was determined to be a hazardous material and its use banned by EPA because of its carcinogenic properties. Water criteria of 0.2 µg/l and 1.0 µg/l have established for boundary and source areas respectively. Concentrations of DBCP in excess of this value have been identified in the groundwater at RMA.

The DBCP plume map is presented in Figure 14. The plumes in general are defined much better than those for some other contaminants, because extensive investigations have been conducted on the distribution of DBCP at RMA. The highest concentrations of this compound were identified in the South Plants Area. A major plume originates in the "A-Neck" area, proceeds northwest, turns north in Section 27, and crosses the Northwest Boundary in Section 22. Another plume originates at the northeast corner of Basin F and proceeds northeast, where it crosses the North Boundary. An area of DBCP concentration has been identified in the Rail Classification Yard, with another plume indicated northeast of this area across 7th Avenue that proceeds to the southern end of the Northwest boundary. The plumes in the Rail Classification Yard and at the southern end of the Northwest Boundary are probably related.

The plumes indicate that the South Plants Area is a major source of DBCP and that it has migrated out of the "A-Neck" area, either from Basin A, or from leaking sewer lines crossing this area. DBCP has been found in the sewage treatment plant, indicating its transport through the sewer. Basin F and the sewer line along the northeast corner of Basin F are sources of the DBCP migrating to the North Boundary.

Diisopropylmethylphosphonate - Diisopropylmethylphosphonate (DIMP) is unique to RMA since it is a byproduct of the manufacture of nerve agent GB. Process wastes were disposed of in the basins at RMA; therefore, its distribution resulted directly from RMA activities. A water criterion of 500 µg/l has been established by the State of Colorado and concentrations in excess of this value are present in the groundwater on and off RMA.

The plume map developed for DIMP is presented in Figure 15. The plume originates in the Basin A area and proceeds through the "A-Neck" area where high concentrations of DIMP were identified south of Basin C. DIMP is distributed around Basin F with high concentrations proceeding from the northeast corner of Basin F to the North Boundary. Concentrations wells below the criteria were identified proceeding to the Northwest Boundary and immediately north of the GB Plant area.

The plumes indicate that Basin A serves as a major source of DIMP. The various closed contours in this area are probably associated with historical brine pits where neutralized off-specification batches of GB waste were disposed of. Basin F also appears to be contributing DIMP to the ground water, but in lesser amounts than Basin A. The high concentration of DIMP south of Basin C is probably related to sources in Basin A.

Dicyclopentadiene - Dicyclopentadiene (DCPD) is a raw material that was used by a lessee for pesticide production in the South Plants; thus its distribution is directly associated with activities in this area of the Arsenal. Water criteria of 1300 µg/l (toxicity) and 24 µg/l (odor) have been established by U. S. Army Medical Biological Research and Development Laboratory (USAMBRDL) and the State of Colorado. Concentrations of DCPD in excess of these values have been identified in groundwater on and off RMA.

The DCPD plume map is presented in Figure 16. Two major plumes have been identified. The first plume originates in the South Plants Area, north into Basin A, and then proceeds northwest through Section 36, along a surface water runoff channel. The second plume is distributed between Basins F and the North Boundary. DCPD also was identified in a small area west of Basin G. The plumes indicate that the South Plants Area serves as a major source of DCPD. The plume northeast of Basin F was found to have higher concentrations of DCPD at the North Boundary, probably indicating a historical migration from the Basin F area with a recent reduction in the amount of DCPD being discharged to the ground water.

Chloride - Very high chloride concentrations in the groundwater at RMA have been a contamination problem for many years. Large amounts of brine and salts containing chloride have been disposed of at the Arsenal. Concentrations

found in the ground water are significantly in excess of the natural concentration found in the area (generally less than 100 mg/ℓ). Therefore, the distribution of chloride on the Arsenal is directly associated with activities at RMA. A secondary drinking water standard of 250 mg/1 (ppm) has been established by the regulatory agencies for chloride. Some of the concentrations of chloride identified around Basin F are so high that the groundwater is unpalatable and toxic to plants.

The chloride plume map is presented in Figure 17. High concentrations of chloride are also found in the South Plants Area. A plume was identified generally distributed through the center of the Arsenal out to the Northwest Boundary. High concentrations of chloride were identified in the "A-Neck" area and west of Basins C and F. A specific plume was identified exiting the northwest corner of Basin F proceeding toward the North Boundary.

The high chloride concentrations identified in the South Plants Area indicate that this area is potentially a significant source of chloride. The high concentration areas identified "A-Neck" area and west of Basins C and F probably originated in Basin A. The plume northeast of Basin F indicates that Basin F is still a major source of chloride to the ground water.

<u>Fluoride</u> - Although fluoride occurs naturally in the ground water in the Denver area, the concentrations of fluoride as high as 5 mg/1 identified in some areas of the Arsenal are significantly higher than the background levels (generally less than 1.5 mg/ℓ). Fluoride, in the form of hydrofluoric acid, was used in the manufacture of nerve agents, and is directly associated with historical RMA activities. A water standard of 2.4 mg/1 (ppm) has been established for fluoride in the RMA ground water. Concentrations of fluoride in excess of this value have been identified in ground water at RMA.

The fluoride plume map is presented in Figure 18. High concentrations of fluoride were identified in the South Plants Area, in a small area on the southwest corner of Basin F, in a small area along the Northwest Boundary, and immediately south of the North Boundary.

The South Plants Area appears to be source of fluoride. The source or sources of fluoride in the north and northwest part of the Arsenal are not so easily identified. The plume near the North Boundary probably represents a historical migration from Basin F, although Basin F does not currently appear to be contributing as much fluoride to the ground water as it once did. The

other areas of high concentrations probably are remnants of historical plumes. The ground-water flow in these areas is relatively slow and the water can be considered somewhat stagnant. As a result, it would take a long time for contaminants in these areas to disperse.

Dithiane/Oxathiane - These compounds are unique to RMA operations, as they are associated with the degradation products of mustard. No criteria have been set for these compounds, but the current lowest reporting limit is 20 µg/l.

The plume maps developed for these data are presented in Figure 19 and 20. The largest concentrations are found in the Basin A area, and migration occurs northwest through the "A-Neck" area to Basin C. An additional path appears for dithiane north of Basin F. It should be noted that the concentrations for dithiane are roughly ten times as high as the oxathiane.

P-Chlorophynyl Methyl Sulfone - P-Chlorophynyl Methyl Sulfone ($PCPMSO_2$) is a chemical associated with the Shell Chemical Company tenant operations. No standard has been established for this compound, but 20 µg/l has been established as the lowest reportable value for chemical analysis. Three areas were found to contain high concentrations of $PCPMSO_2$, i.e., Basins A, C, and F (Figure 21).

Summary of Ground-Water contaminant Migration

As indicated by the plume maps, there are several general contaminant migration pathways across the Arsenal. As expected, these pathways tend to follow the major ground-water flow paths, as indicated in Figure 22, since the ground water is the present transport mechanism for the contaminants. Those contaminants originating in the South Plants Area and Basin A tend to migrate through the "A-Neck" area where a split occurs with migration both to the northwest and the north. No contaminant migration to the east or northeast from Basin A has been noted, probably because of the flow divide located in this area. Only intermittent contaminant migration to the west and northwest from the South Plants Area has been noted, although the potential for a major exodus of migration exists. Slight variations in the ground-water gradients in the South Plants Area could result in such a migration.

The northwestward component of contaminant migration out of the "A-Neck" area follows a narrow, shallow, submerged channel into Section 27, where it turns north into Section 22, and then back northwest where it intercepts the Northwest Boundary (Figure 22). This pathway has been detailed only recently as a result of extensive investigations on DBCP migration. Any contaminants passing through the "A-Neck" area in the future thus could be transported to the Northwest Boundary. A smaller component of flow from this area proceeds north under Basins C and F and on to the North Boundary. The rate at which water is transported through this zone is much decreased because of the flow that must occur through the Denver sands.

Most of the contaminants originating in the Basin F area migrate to the northwest until they reach a point approximately underlying the line between Sections 23 and 24, where the flow path turns north and intercepts the migration of contaminants to the east in Section 24. The alluvium in the western half of Section 23 is dry, thus limiting contaminant migration in that direction. Migration of contaminants to the west from Basin F has been noted only to a small degree. Much of the alluvium in this area is dry and what migration does occur probably follows small, unidentified, submerged channels.

The only other contaminant migration pathway noted is located in the west-central part of the Arsenal where DBCP was spilled in the Rail Classification Yard and has migrated a short distance north. The plume disappears, and then reappears on the north side of 7th Avenue, where the pathway proceeds northwest to intercept the Northwest Boundary. This pathway probably includes some form of surface transport across 7th Avenue. The large volume of groundwater flow to the west and northwest in this area would result in the dilution of the contaminants to a concentration level below detectable limits, thus preventing any continuous plume in this area.

Significant migration of contaminants into the Denver water bearing units has not been identified, except in those areas where there is direct contact between the alluvium and Denver sands, and in some cases where the alluvium is dry and the major flow of ground water occurs through the Denver formation. In any case, the contaminants generally are transported back into the alluvium at some point where the alluvium again becomes saturated by the artesian flow component from the Denver formation into the alluvium.

No new contaminant sources were identified from the results of the Regional Study. Historical sources such as the South Plants Area and the basins still

appear to be the major sources of contamination to the ground water. The quality of the ground water flowing into the Arsenal appears to be good with the possible exception of some low concentrations of organic solvents. The current plume distributions on the Arsenal appear to be following the historical trends with some slight movements of contaminant fronts over the past 3 to 5 years. Contaminant concentrations do not appear to have increased or decreased much over this period of time.

Investigation of Contaminant Stratification Along the Northwest Boundary

As previously discussed, three Regional well sites (NW 1, 4, and 11) were selected for installation of multi-piezometers in the alluvial aquifer to determine if contaminant stratification was occurring. These three sites were selected due to their proximity to the northwest boundary which was of primary concern early in the study and because the saturated thicknesses in the alluvium at these sites were large and adequate for installation of multi- piezometers. There was concern that if contaminants were migrating across the northwest boundary in a stratified flow at low concentrations, the contaminants might not be detected in samples from a single piezometer screening a larger saturated thickness. In this situation, the concentration of a contaminant could be diluted to below the detectable limit.

Only very low or no concentration of organic contaminants were found in piezometers associated with these well sites. At NW1, trichloroethylene at 12.4 ppb was found in the sample collection from the deepest piezometer in the alluvium (5th out of 5) while the trichloroethylene concentrations in the samples from the other piezometers were below the detection level of 10 ppb. This represents only a slight difference in concentration. No organic contaminants were found above the detection levels in the samples collected from the two piezometers at NW4. At NW11, concentrations of chloroform 13.5, 11.1, and 16.9 ppb were found in the samples collected from the three alluvial piezometers at that site representing only slight concentration differences. With respect to the inorganic contaminants analyzed for, the concentrations in the samples from the various piezometers at each site were found to remain constant with depth. Thus, based on the limited data collected, contaminant stratification does not appear to be occurring in the area associated with these well sites.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results of the work conducted in this study, the following conclusions have been made:

a. The only new ground-water contaminants identified on the Arsenal with any significant distribution are a number of volatile organic solvents including toluene, xylene, benzene, chloroform, and di-, tri-, and tetrachloroethylene. These contaminants are scattered across the Arsenal with the highest concentrations found in the South Plants Areas.

b. Migration of the large number and concentrations of contaminants from the South Plants Area appears to be occurring at only a very slow rate.

c. Contaminant migration across the Arsenal appears to be following the historical trends with migration along the major ground-water flow paths to the north and northwest.

d. No contaminant migration to the east or northeast of Basin A could be identified.

e. No significant contaminant migration into the Denver water bearing units could be identified.

f. Contaminant concentrations in the ground water do not appear to have increased or decreased significantly over the past 3 to 5 years.

g. No new contaminant sources could be identified based on the ground-water contaminant concentrations and distributions found.

Recommendations

Based on the results of the work conducted in this study, the following actions are recommended:

a. Sampling and analysis of wells in the areas of the contaminant plumes should be continued on a regular basis. This data will be needed to define changes in contaminant concentrations and distributions as migration from the source areas continues. Such data will also indicate the effect that control structures and activities have on contaminant migration.

b. A detailed hydrogeological and contaminant distribution investigation is needed in the area north and northwest of the Rail Classification Yard to define the distribution and migration potential of DBCP in the area. Information is needed to determine if the DBCP plumes in the Rail Classification Yard and on the southern end of the Northwest boundary are actually related or if they result from separate sources. This investigation would entail placement of additional wells and a sampling and analysis program.

REFERENCES

1. Stoller, R. L., "Evaluation of the Hydrogeologic System and Contamination Migration Patterns at Rocky Mountain Arsenal," Geraghty and Miller, Inc., January, 1981.
   RIC Control No: 81293R05.

2. May, J. H., "Regional Groundwater Study of Rocky Mountain Arsenal, Report 1: Hydrogeological Definition, Geotechnical Laboratory, US Army Engineer Waterways Experiment Station, July 1982.
   RIC Control No: 82295R01

3. "Recommended Groundwater Sampling Protocol and Monitoring Program for RMA, Denver, Colorado," ERTEC Western, Inc., January, 1982.
   RIC Control No: 82039R02

TABLES

Table 1

Distribution of Analytical Effort and Respective Detection Limits

	Parameter	Detection Limit
	RMA Analytical Systems Branch Laboratory	
Organic		
	DBCP	0.2 μg/ℓ
	DIMP	10.0 μg/ℓ
	DPCD	24.0 μg/ℓ
	DMMP	10.0 μg/ℓ
	Sulfone	20.0 μg/ℓ
	Sulfoxide	20.0 μg/ℓ
	Dithiane	20.0 μg/ℓ
	Benzothiazole	20.0 μg/ℓ
	Aldrin	1.0 μg/ℓ
	Endrin	0.2 μg/ℓ
	Dieldrin	1.0 μg/ℓ
	Isodrin	1.0 μg/ℓ
Inorganic		
	Ca	0.2 μg/ℓ
	Mg	0.5 μg/ℓ
	F	0.2 μg/ℓ
	Cl	20.0 μg/ℓ
	Na	20.0 μg/ℓ
	K	2.0 μg/ℓ
	SO_4	50.0 μg/ℓ
	Midwest Research Institute Laboratory	
Organic		
	Toluene	10.0 μg/ℓ
	Xylene	10.0 μg/ℓ
	Benzene	10.0 μg/ℓ or lower
	Dichloroethylene	10.0 μg/ℓ
	Trichloroethylene	10.0 μg/ℓ
	Tetrachloroethylene	10.0 μg/ℓ
	Chloroform	10.0 μg/ℓ
	Tetramethyl Urea	10.0 μg/ℓ
	Carbon Tetrachloride	10.0 μg/ℓ
	Napthalene	10.0 μg/ℓ

Table 2

Sampling Locations and Analytical Requirements for the Regional Quantitative Investigation

Area I - Southern/Eastern

Sampling Locations - E2, E3, E4, E7, E8, E11, E13, E14, E15, SP3, SP17, SP18, SP19, SP20, SP21

Approximately 50 wells

Analytical Requirements - Toluene, Xylene, Benzene, Dichloroethylene, Trichloroethylene, Tetrachloroethylene, Chloroform, Sulfone, Sulfoxide, Dithiane, Benzothiazole, Tetramethyl Urea, Napthalene, Ca, Mg, F, Cl, Na, K, SO_4

Area II - Western

Sampling Locations - NW1, NW2, NW3, NW4, NW5, NW6, NW7, NW8, NW9, NW10, NW11, NW12, NW20, NW21, NW22, NW23, NW24, NW25, NW26, NW27, SP8, SP11, SP13, 1*, 2*, 3*, 4*

Approximately 85 wells

Analytical Requirements - Toluene, Xylene, Benzene, Dichloroethylene, Trichloroethylene, Tetrachloroethylene, Chloroform, Sulfone, Sulfoxide, Dithiane, Benzothiazole, Tetramethyl Urea, Napthalene, Ca, Mg, F, Cl, Na, K, SO_4, DBCP, DIMP, DCPD, DMMP, Aldrin, Dieldrin, Isodrin, Endrin

Area III - Central

Sampling Locations - N1, N2, N3, N4, N5, N6, SP1, SP2, SP4, SP5, SP6, SP7, SP9, SP10, SP12, SP14, SP15, SP16, E1, 13*, 14*, 15*, 16*, 17*

Approximately 60 wells

Analytical Requirements - Toluene, Xylene, Benzene, Dichloroethylene, Trichloroethylene, Tetrachloroethylene, Chloroform, Sulfone, Sulfoxide, Dithiane, Benzothiazole, Tetramethyl Urea, Napthalene, Carbon Tetrachloride, Ca, Mg, F, Cl, Na, K, SO_4, DBCP, DIMP, DCPD, DMMP, Aldrin, Dieldrin, Isodrin, Endrin

(Continued)

* Indicates additional well site sampled in the Quantitative Program.

Table 2 (Concluded)

Area IV - Northern

Sampling Locations - NW13, NW14, NW15, NW16, NW17, NW18, NW19, E5, E6, E9, E10, E12, 5*, 6*, 7*, 8*, 9*, 10*, 11*, 12*

Approximately 50 wells

Analytical Requirements - Toluene, Xylene, Benzene, Dichloroethylene, Trichloroethylene, Tetrachloroethylene, Chloroform, Sulfone, Sulfoxide, Dithiane, Benzothiazole, Tetramethyl Urea, Napthalene, Ca, Mg, F, Cl, Na, K, SO_4, DBCP, DIMP, DCPD, DMMP, Aldrin, Dieldrin, Isodrin, Endrin

* Indicates additional well sites sampled in the Quantitative Program.

Table 3

Water Quality Criteria

Parameter	Criteria	Reference*
Aldrin	0.2 µg/l	d
Benzene	6.6 µg/l	c
Chloride	250 µg/l	b
Chlorobenzene	488 µg/l	c
Dibromochloropropane (DBCP)	0.2 µg/l	e
Dicyclopentadiene (DCPD)	24 µg/l	e
Diisopropylmethylphosphonate (DIMP)	500 µg/l	e
Dieldrin	0.2 µg/l	d
Dithiane	20 µg/l	d
Endrin	0.2 µg/l	a
Fluoride	2.4 mg/l	a
Oxathiane	20 µg/l	d
p-Chlorophenylmethyl Sulfone ($PCPMSO_2$)	20 µg/l	d
Toluene	14.3 mg/l	c

* Source of criteria
a. Primary Drinking Water Standard
b. Secondary Drinking Water Standard
c. Human Health Criteria for 10^{-5} Risk Level
d. Detection of Analytical Method
e. RMA agreement with State of Colorado.

FIGURES

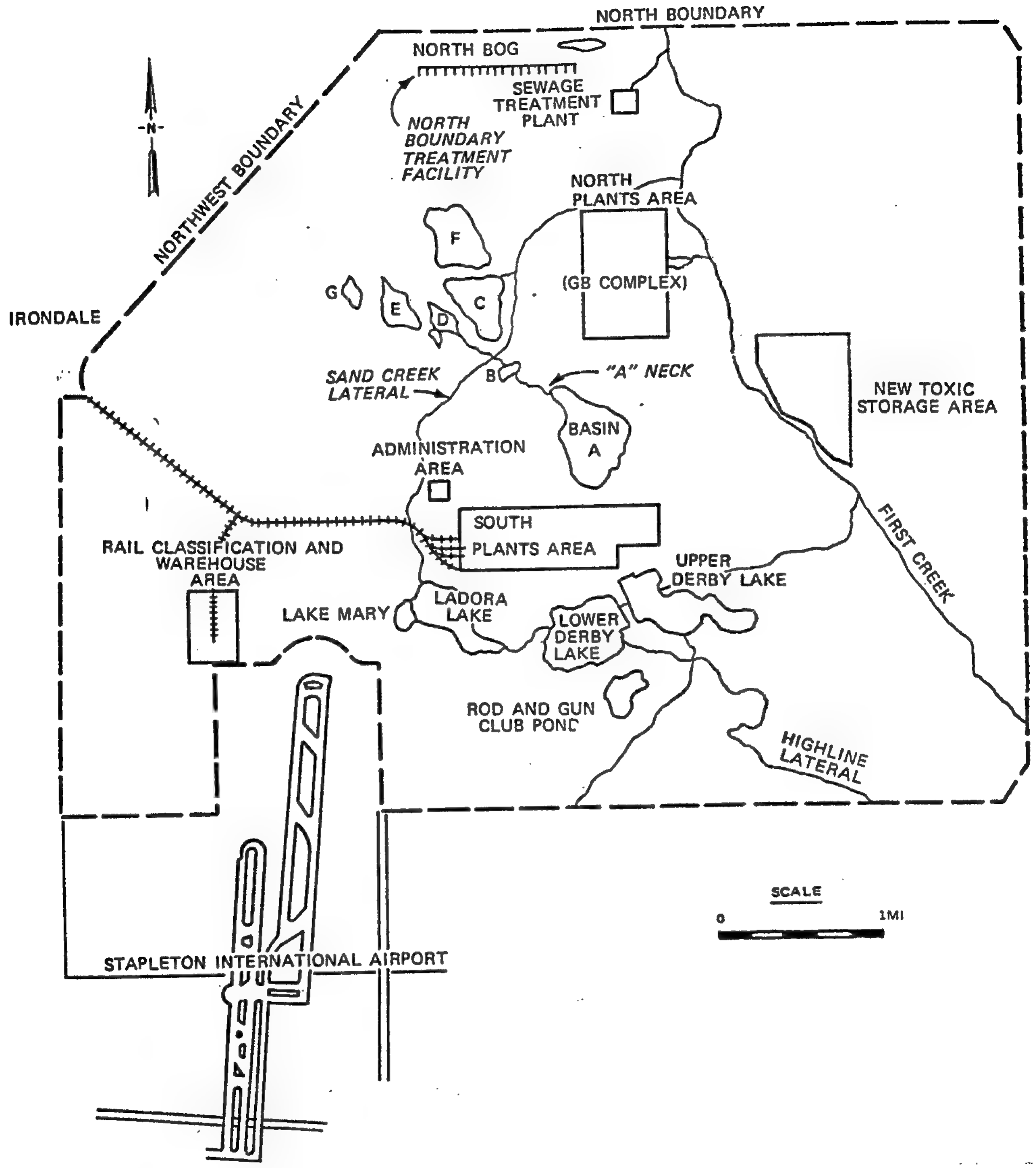

Figure 1. General map of Rocky Mountain Arsenal

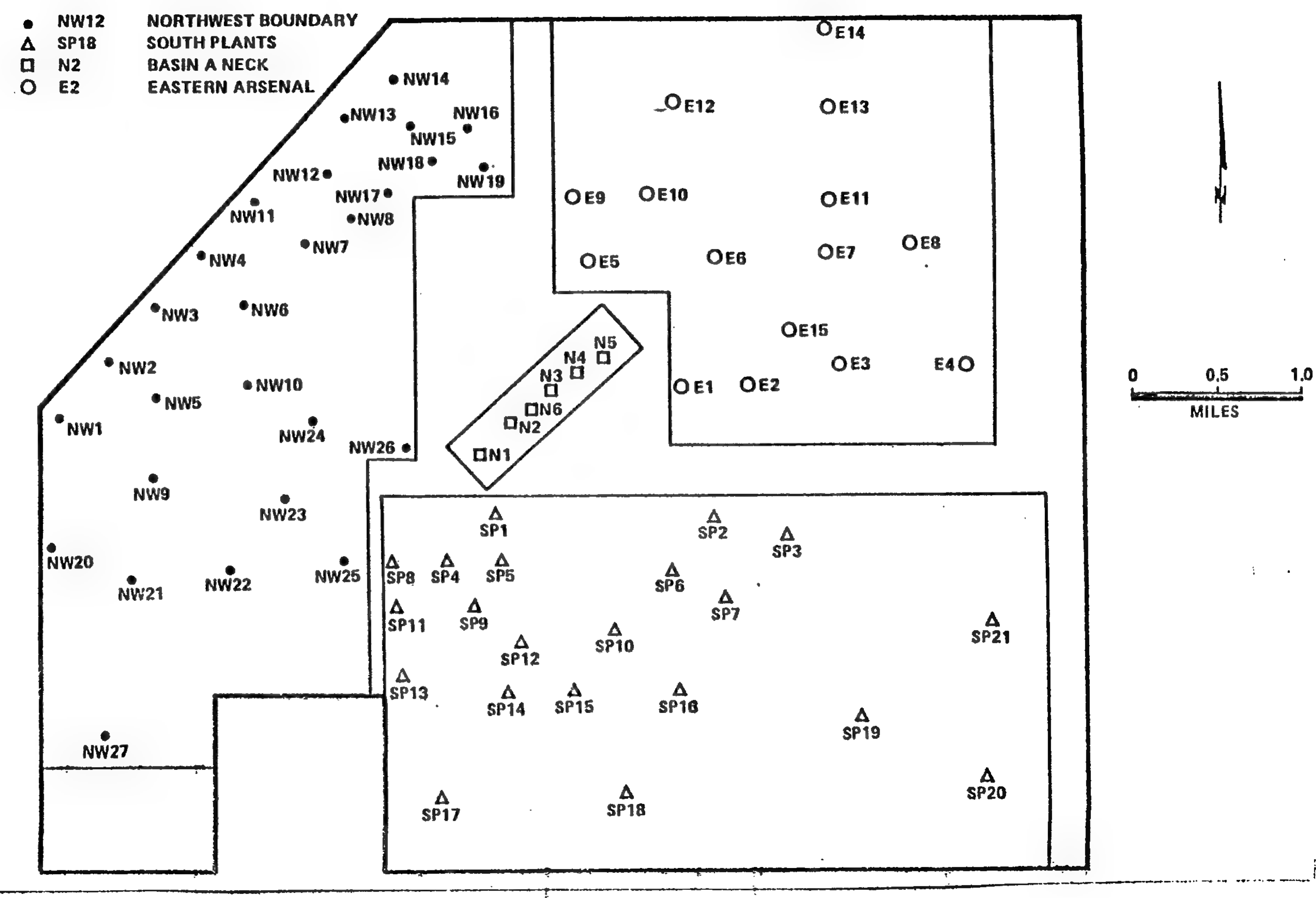

Figure 2. Well locations for Regional Groundwater Study

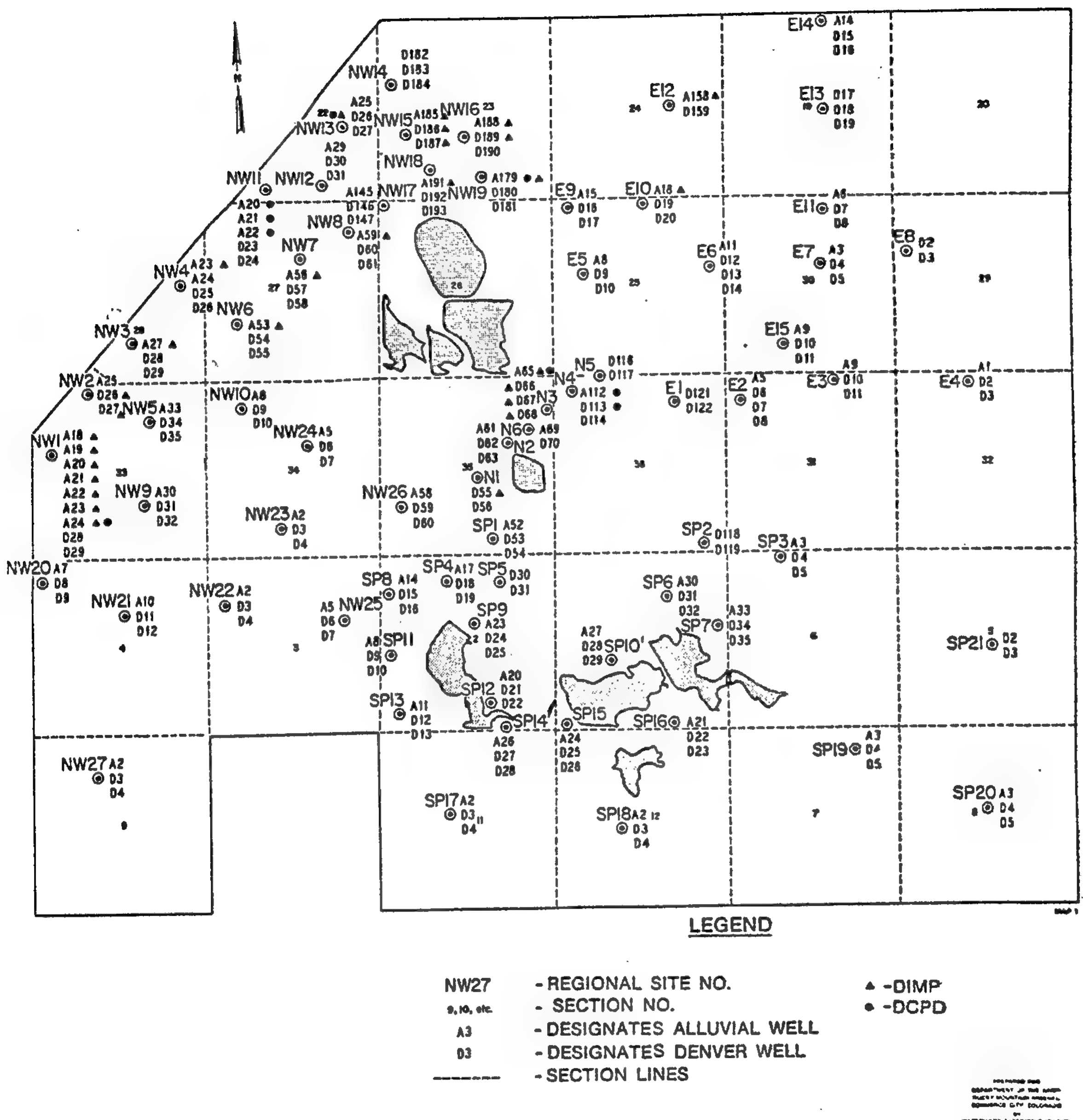

Figure 3. Qualitative distribution of DIMP and DCPD

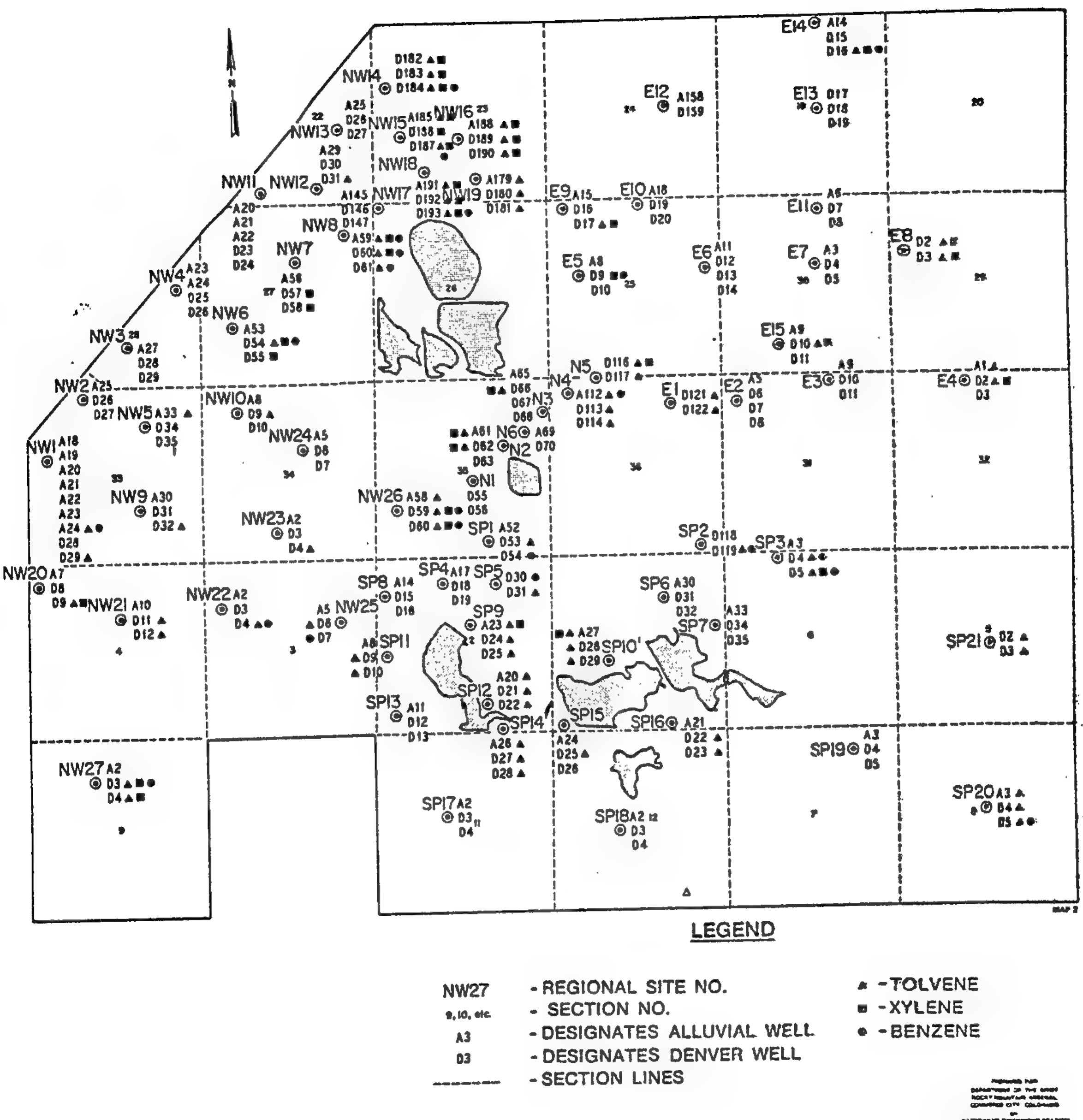

Figure 4. Qualitative distribution of toluene, xylene, and benzene

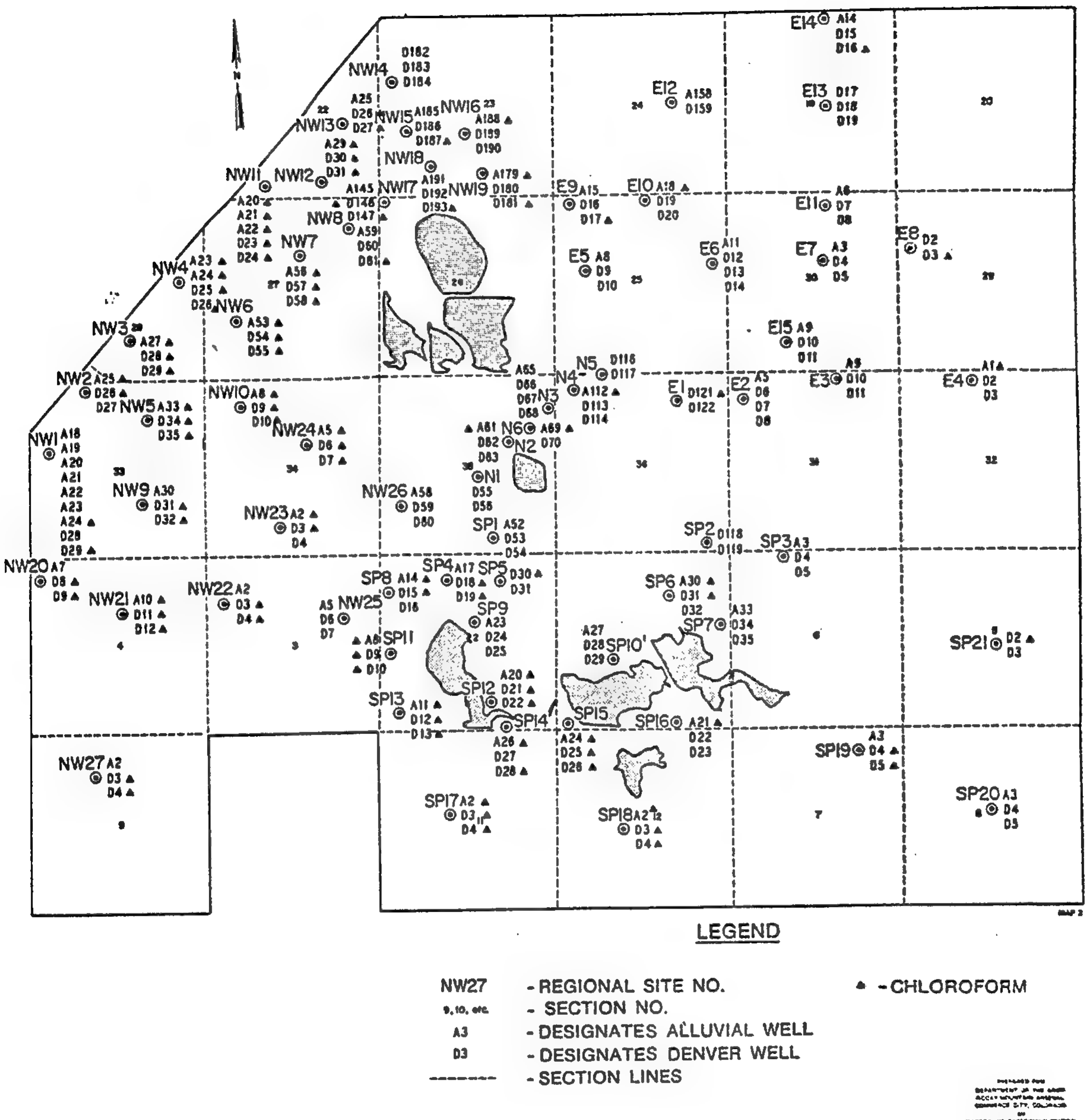

Figure 5. Qualitative distribution of chloroform

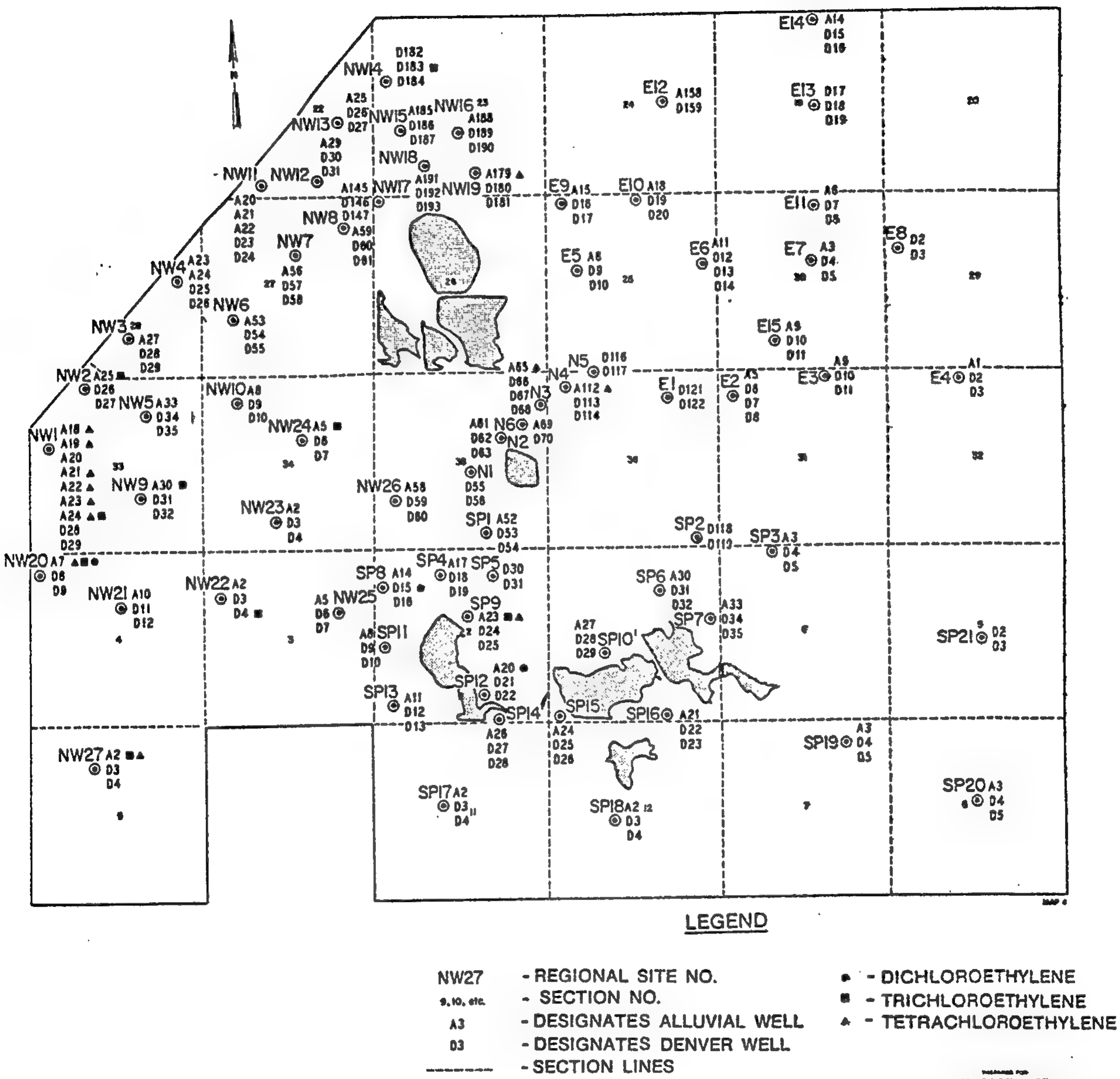

Figure 6. Qualitative distribution of di-, tri-, and tetrachloroethylene

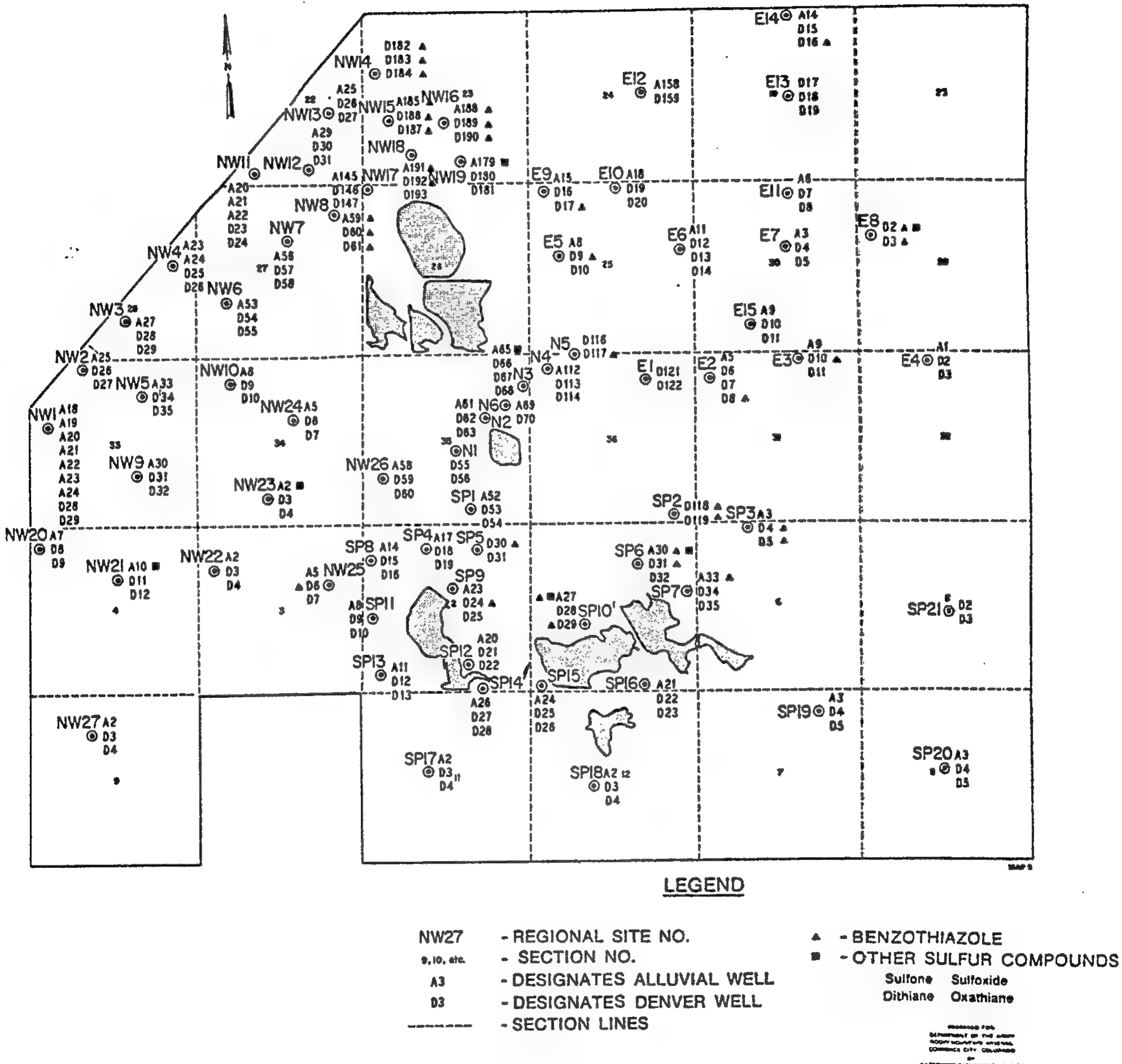

Figure 7. Qualitative distribution of benzothiazole and other organo-sulfur compounds

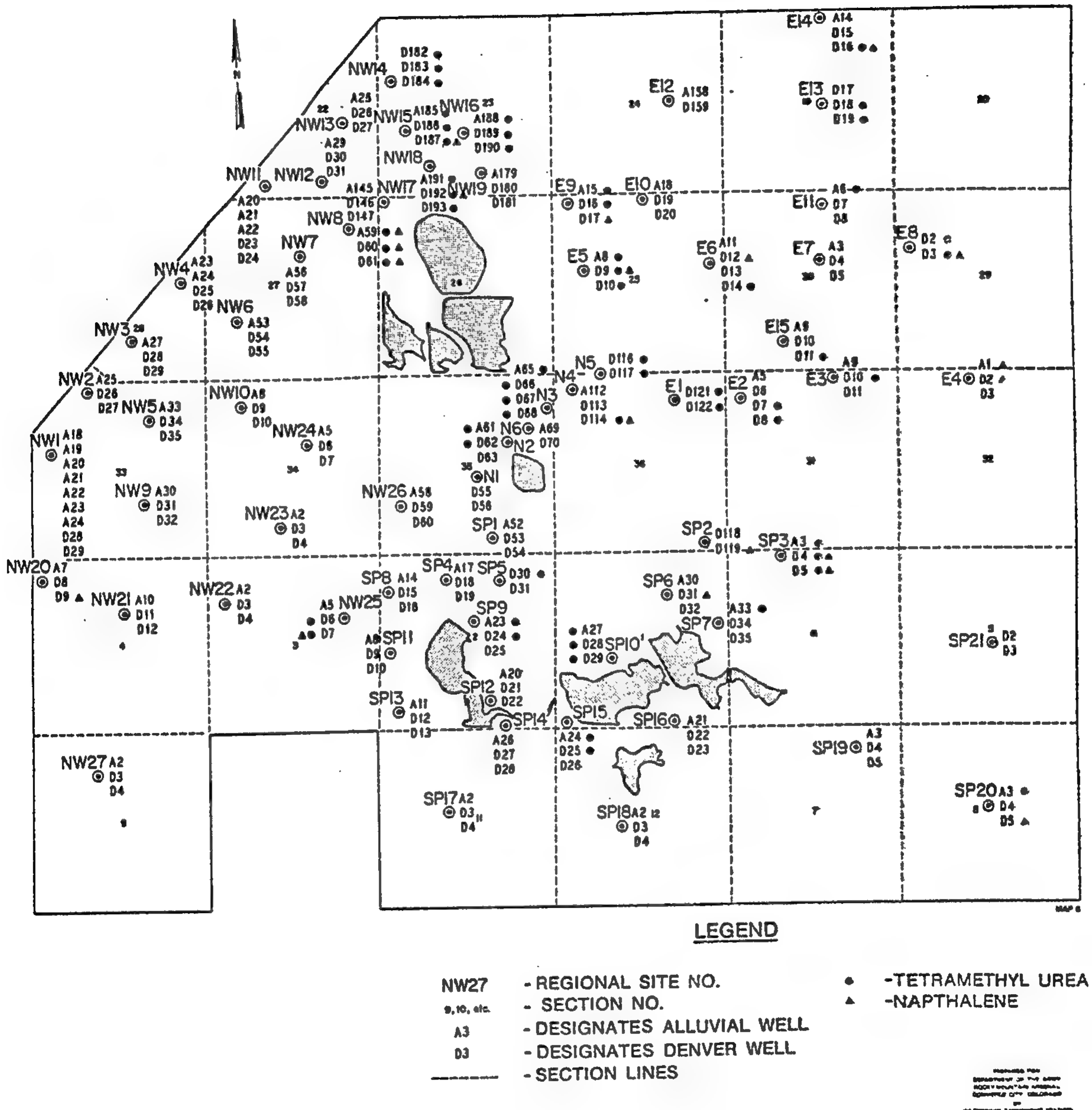

Figure 8. Qualitative distribution of tetramethyl urea and napthalene

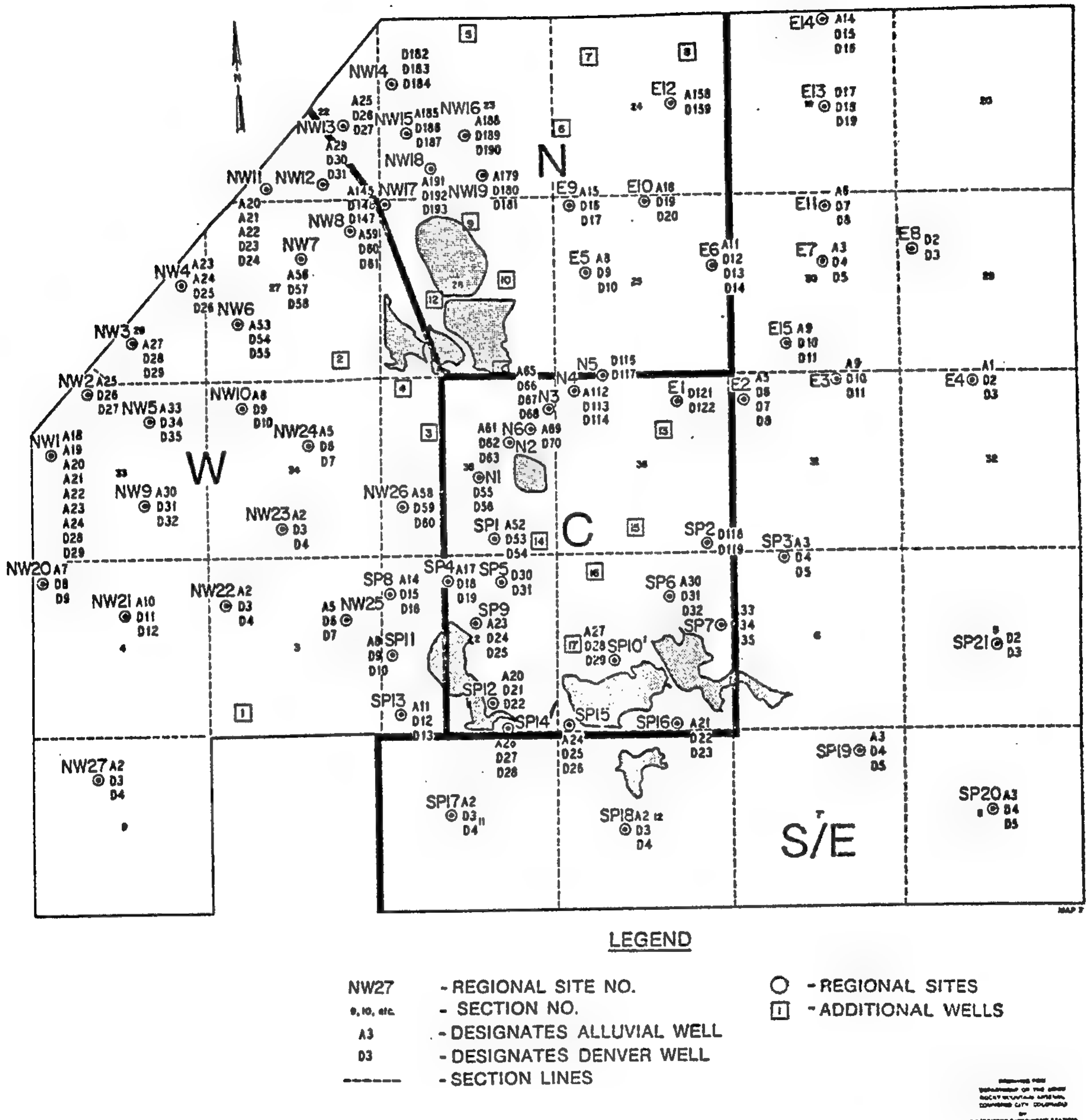

Figure 9. Groundwater sampling locations for the Quantitative phase of the Regional Groundwater Study

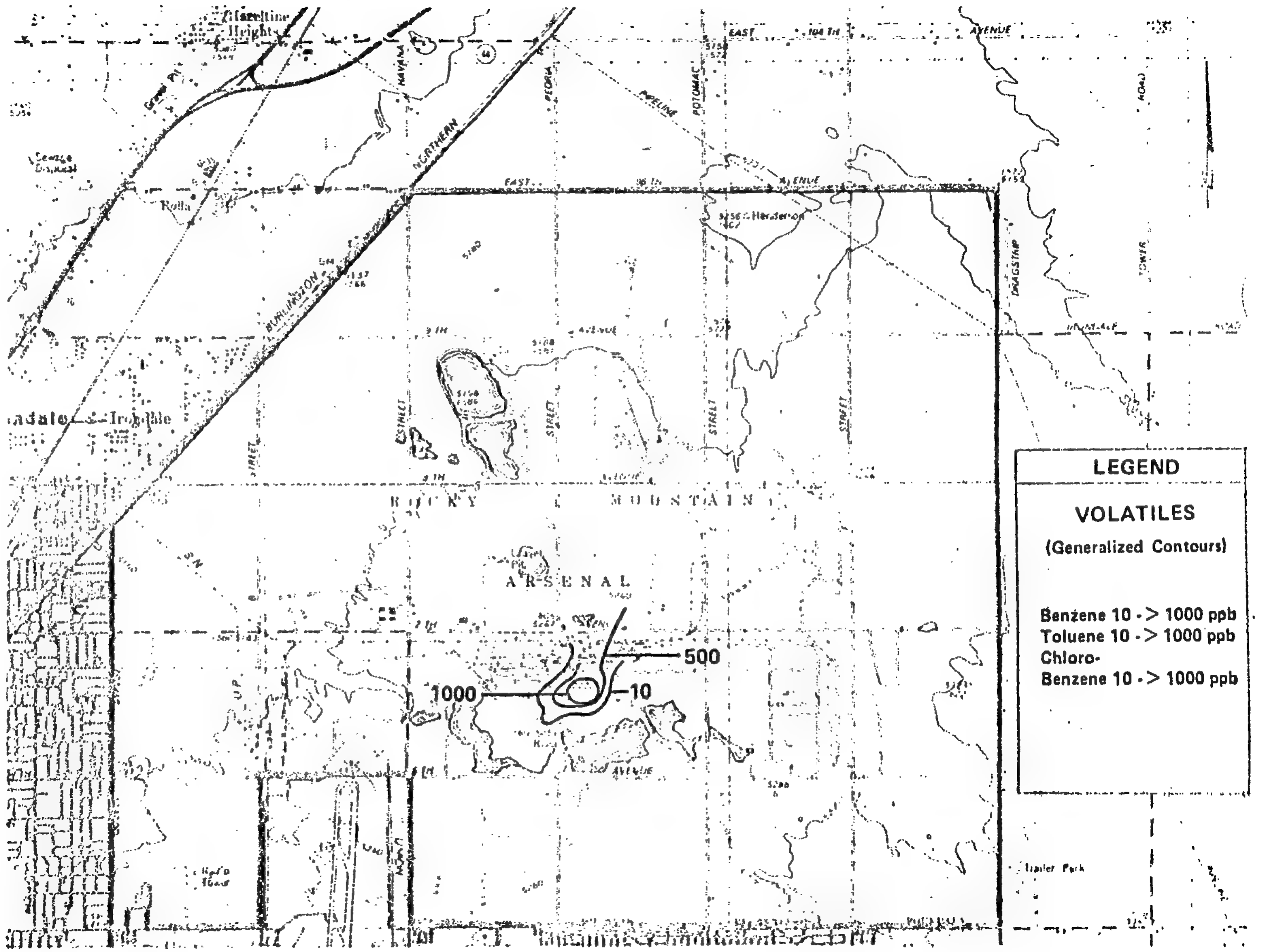

Figure 10. Quantitative distribution of volatile organics

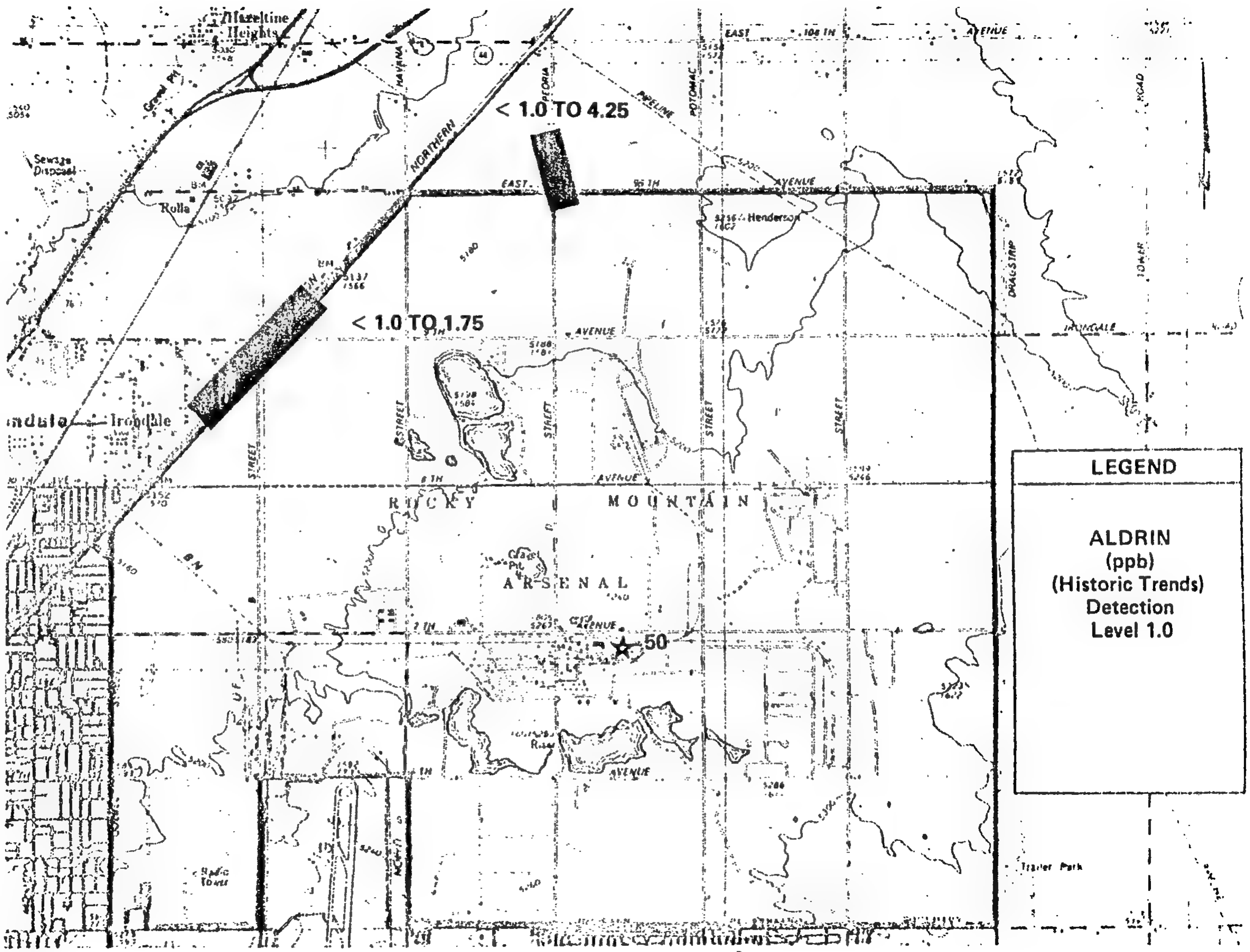

Figure 11. Quantitative distribution of aldrin

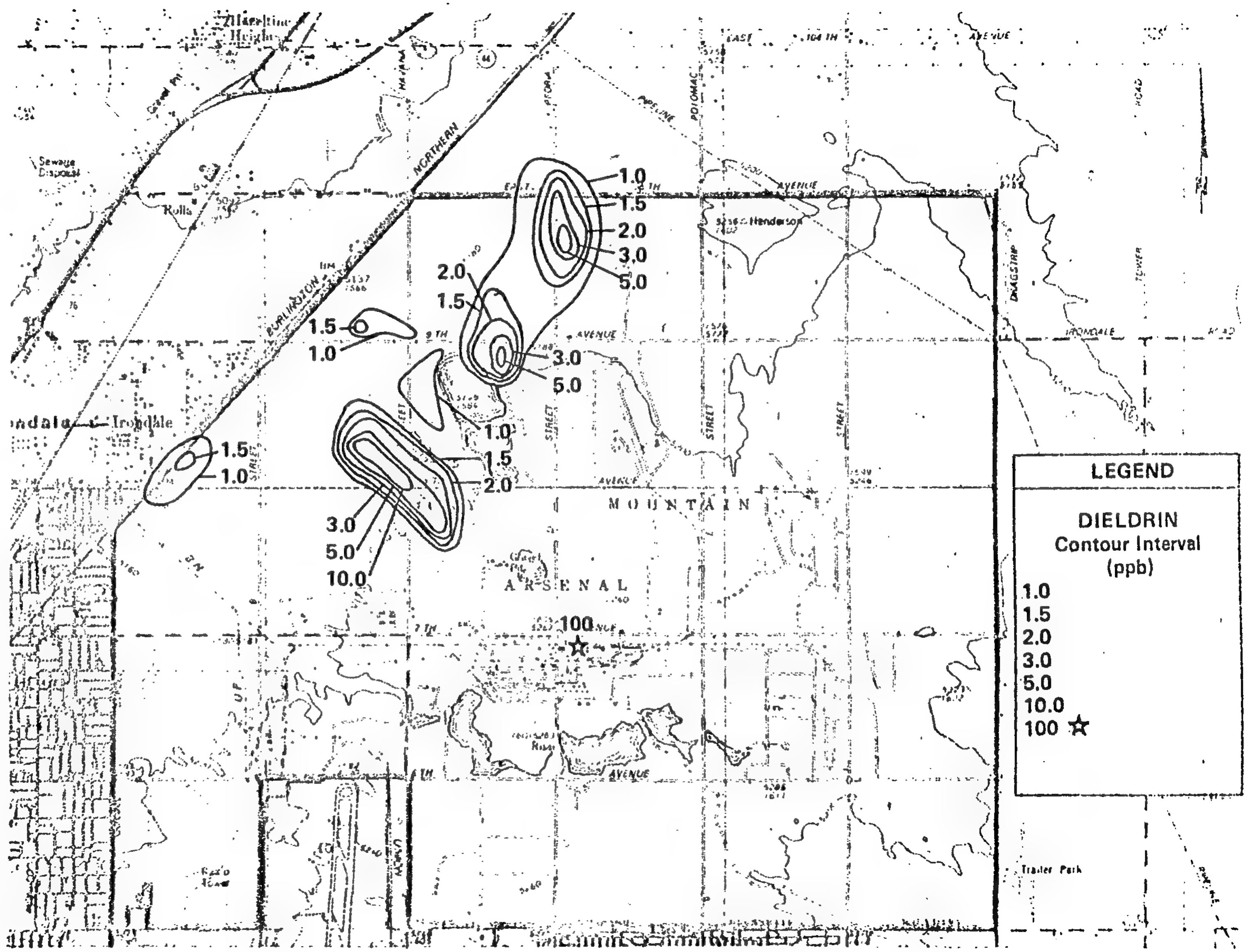

Figure 12. Quantitative distribution of dieldrin

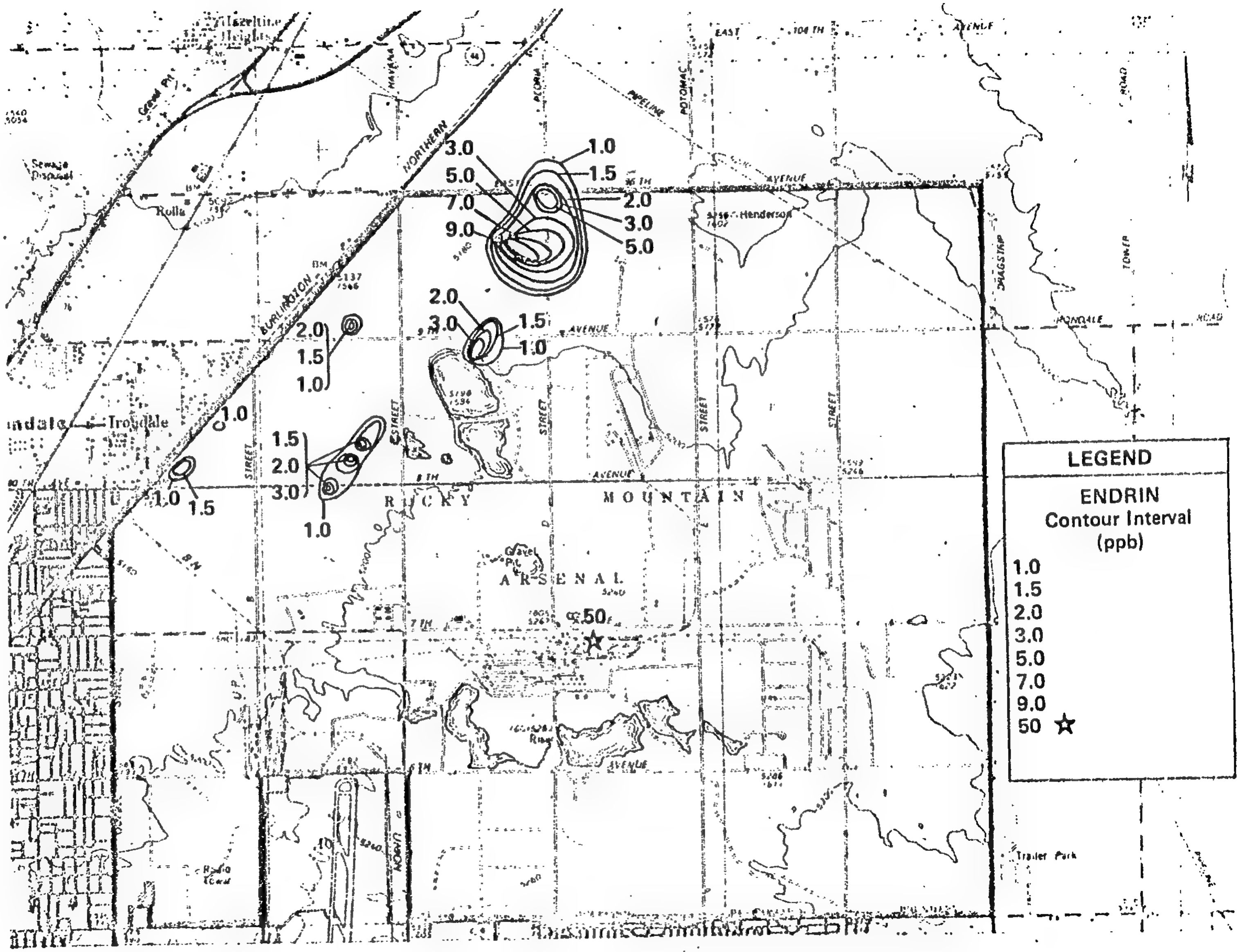

Figure 13. Quantitative distribution of endrin

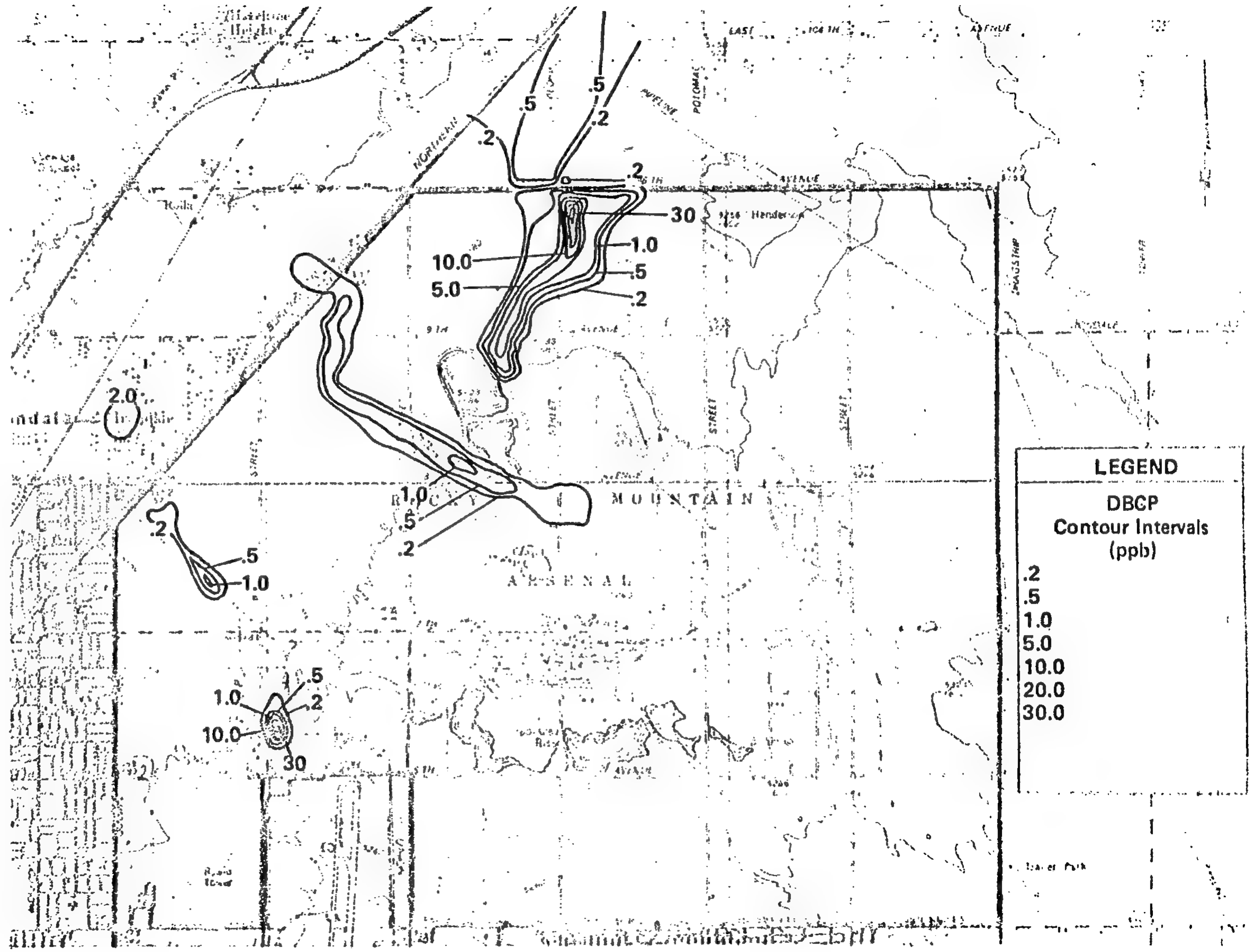

Figure 14. Quantitative distribution of DBCP

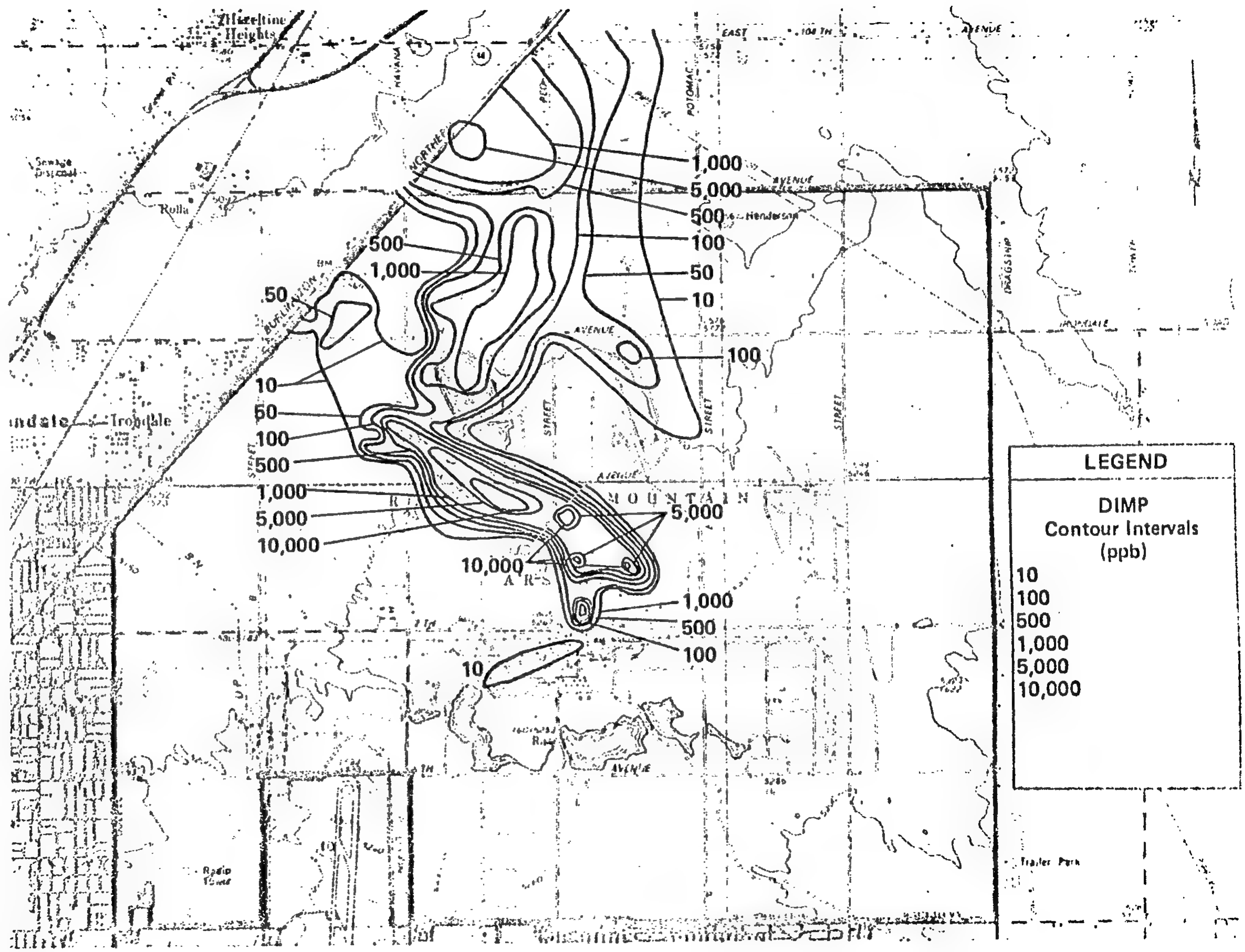

Figure 15. Quantitative distribution of DIMP

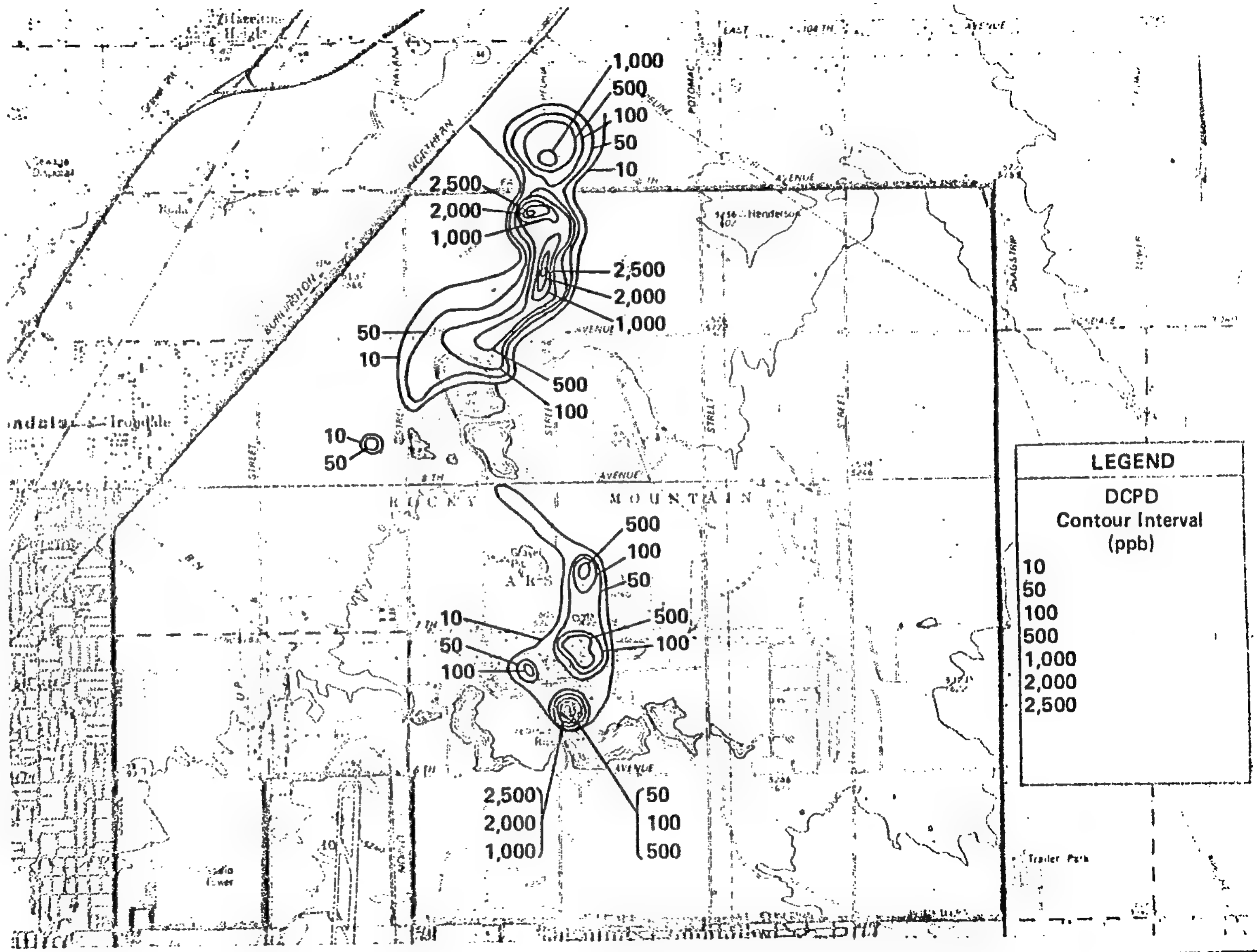

Figure 16. Quantitative distribution of DCPD

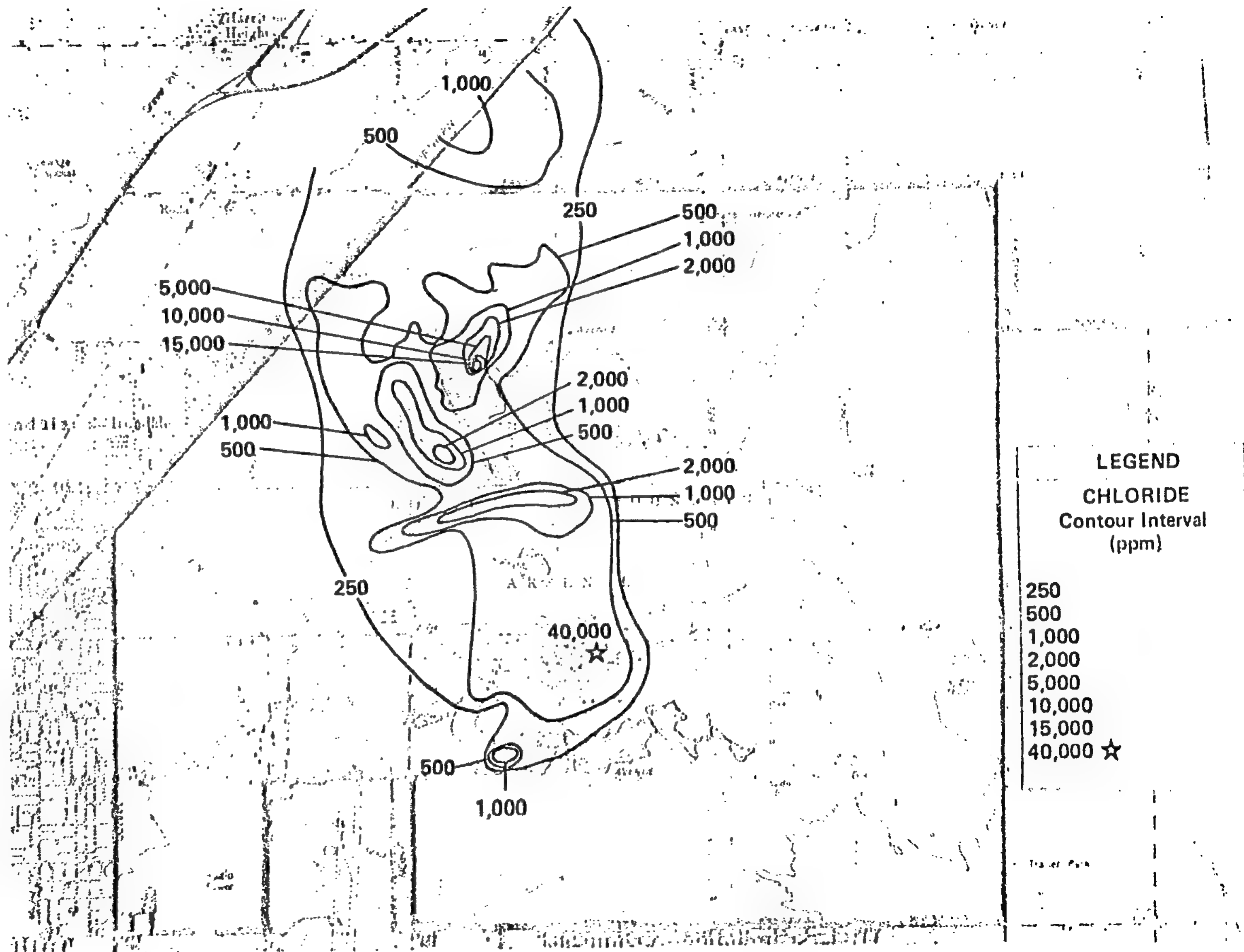

Figure 17. Quantitative distribution of chloride

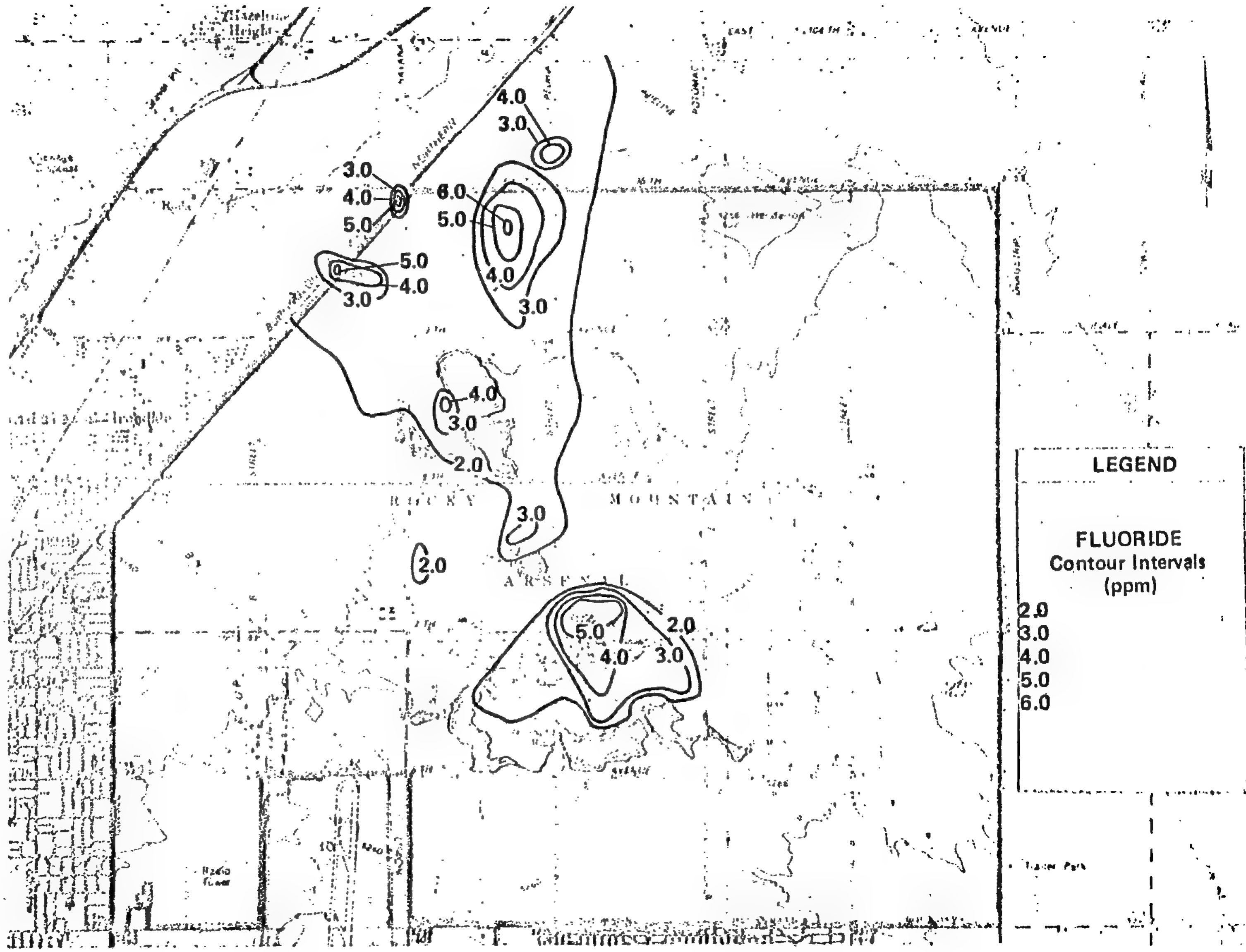

Figure 18. Quantitative distribution of flouride

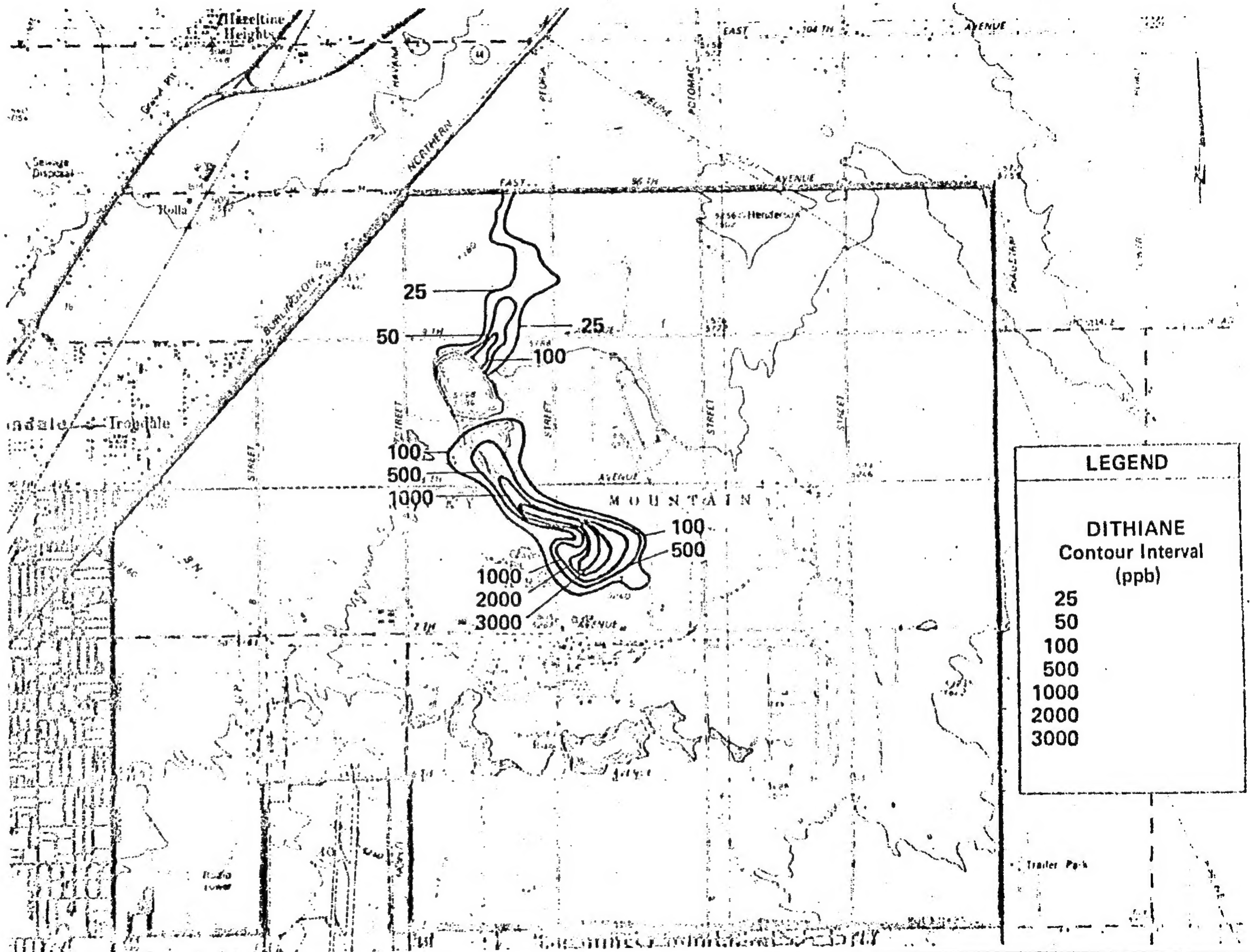

Figure 19. Quantitative distribution of dithiane

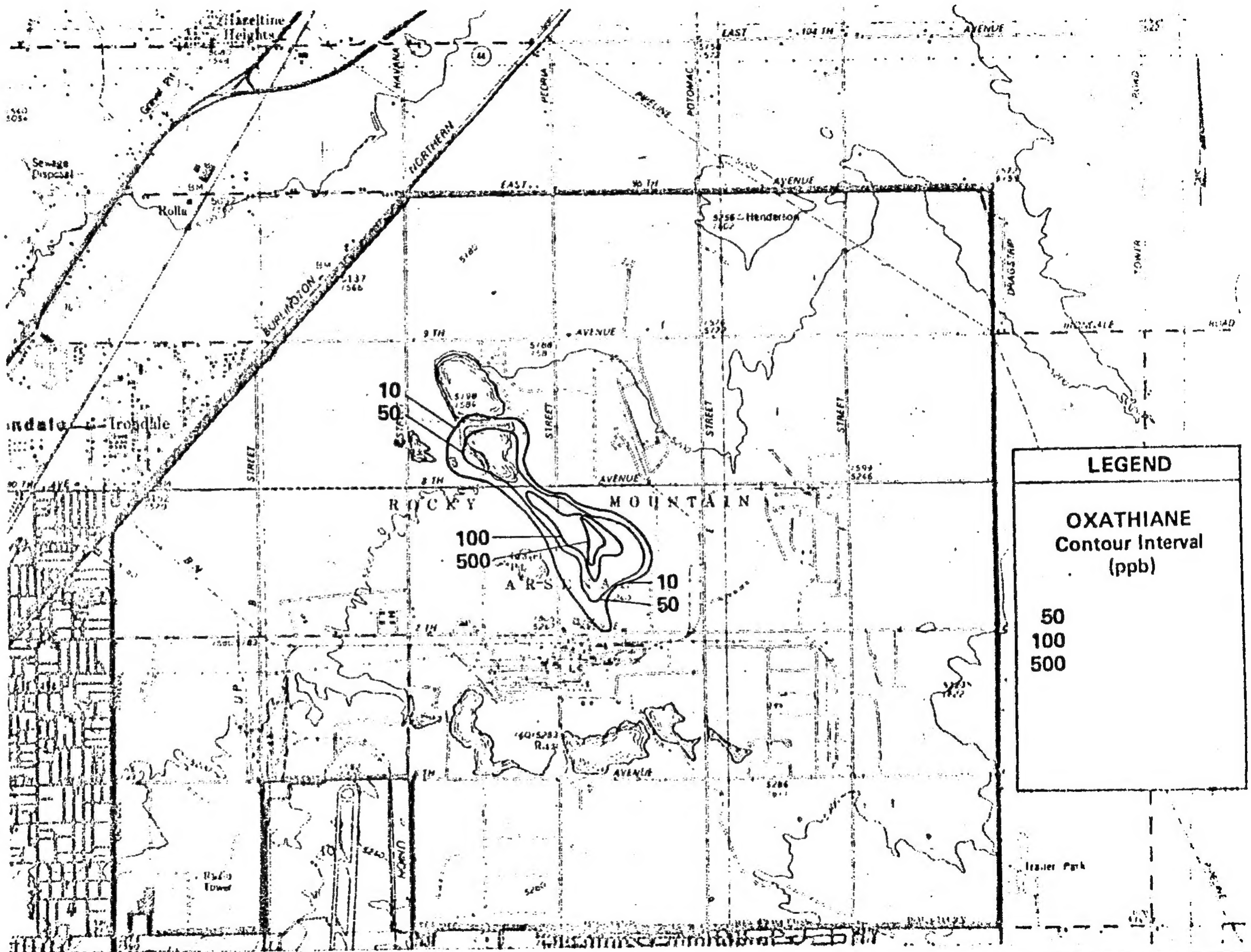

Figure 20. Quantitative distribution of oxathiane

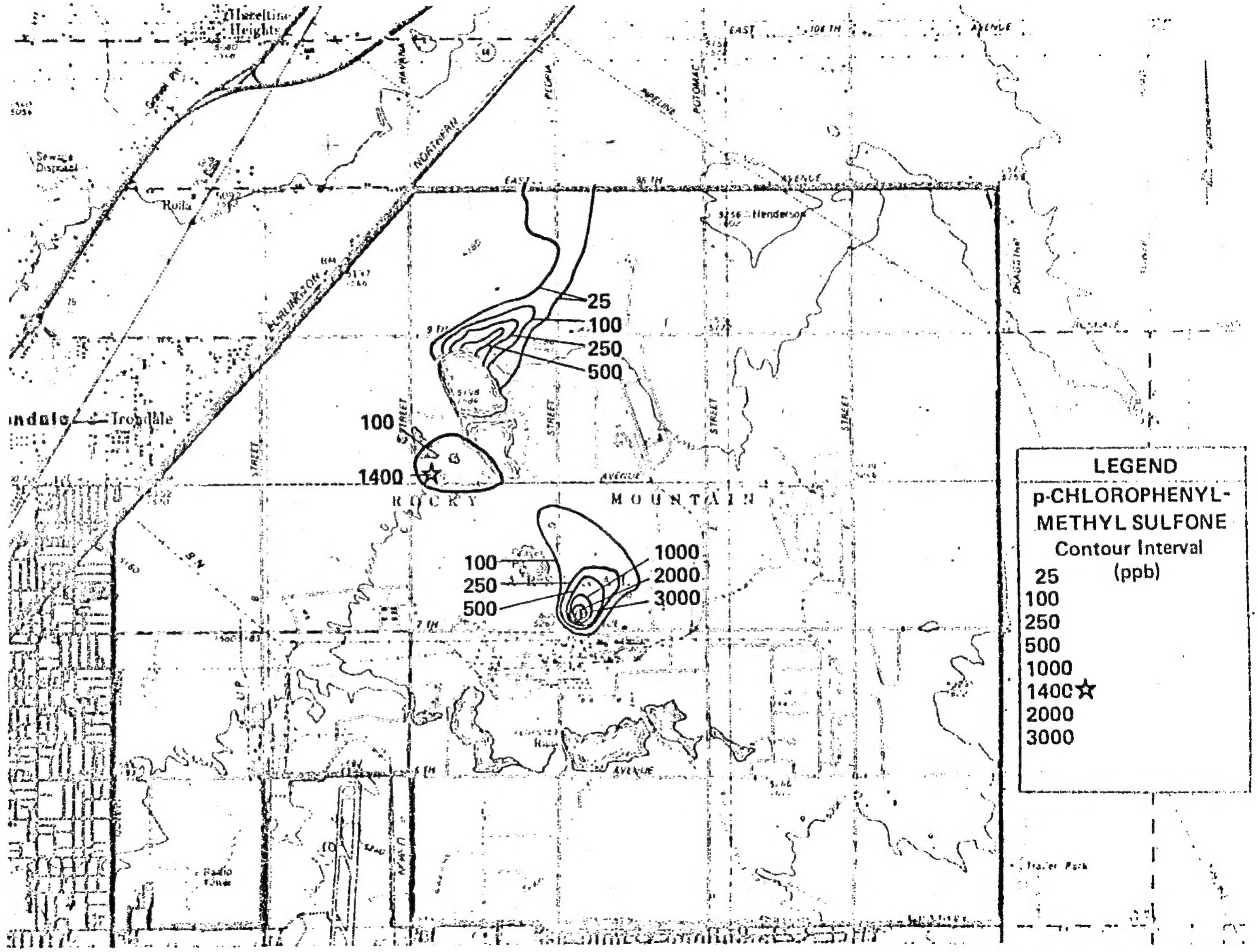

Figure 21. Quantitative distribution of p-chlorophenylmethyl sulfone

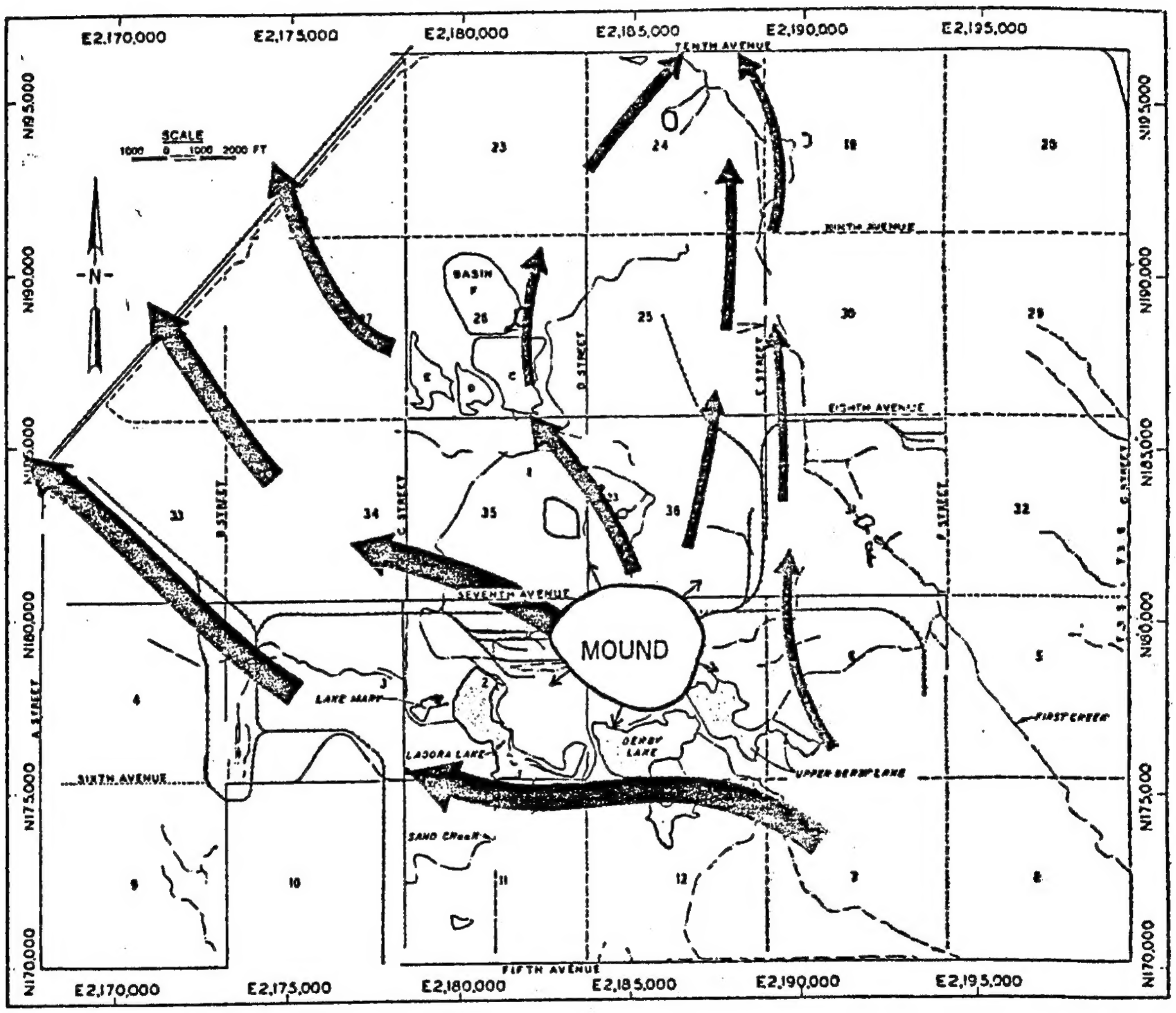

Figure 22. Major groundwater flow paths at Rocky Mountain Arsenal